NUCLEAR WINTER

JOINT HEARING

BEFORE THE

SUBCOMMITTEE ON NATURAL RESOURCES,
AGRICULTURE RESEARCH AND ENVIRONMENT

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY

AND THE

SUBCOMMITTEE ON
ENERGY AND THE ENVIRONMENT

OF THE

COMMITTEE ON
INTERIOR AND INSULAR AFFAIRS
U.S. HOUSE OF REPRESENTATIVES

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NUCLEAR WINTER

THURSDAY, MARCH 14, 1985

House of Representatives, Committee on Science and Technology, Subcommittee on Natural Resources, Agricultural Research and Environment, and the Committee on Interior and Insular Affairs, Subcommittee on Energy and the Environment,
Washington, DC.

The subcommittees met, pursuant to call, at 9:30 a.m., in room 2318, Rayburn House Office Building, Hon. Morris K. Udall (chairman of the Subcommittee on Energy and Environment) presiding.

Mr. Udall. The hearing will be in session.

This is a joint hearing today of the Committee on Science and Technology, the Subcommittee on Natural Resources, Agricultural Research and Environment, chaired by the gentleman from New York, Mr. Scheuer, and the Subcommittee on Energy and Environment of the Interior Committee, which I have the honor to chair.

Our purpose today is to discuss nuclear winter. This is a matter of such importance that Mr. Scheuer and I decided to hold a joint hearing. We had scheduled separate hearings, and this seemed a more efficient and effective way to go.

I hope that today's testimony will result in a better understanding of questions that nuclear winter immediately calls to mind. What is it? What are its effects? How does it change our thinking about nuclear war? What should nuclear winter cause us to do that we had not done before we knew about it? And other questions.

Some of today's witnesses will describe the nuclear winter phenomena. Others will tell us how they believe our strategic posture should be modified in light of it.

Before we begin, I want to say that it troubles me that we were nearly into the fifth decade of the nuclear era before our military planners explicitly accepted the potential destructiveness of the climatic effects of nuclear war. Such effects, it is now believed, could rival the damage resulting from the more familiar effects of blast, fire, and fallout. It is worth reflecting upon the consequences of an attack by our Strategic Air Command upon the Soviet Union had it occurred in the late fifties or early sixties. At that time, by all appearances, we possessed an overwhelming superiority; our military leaders had reason to assure the President that the United States could attack the Soviet Union and expect little or no retaliation.

If, on the basis of such advice, the President had decided in such time of crisis to launch an attack, our targeting doctrine, I have been told, would have led to the detonation of thousands of megatons over Russian cities. The result would have extended far beyond destruction of the Soviet society. Some scientists now believe that such an attack would very likely have created catastrophic climatic changes in the Earth's Northern Hemisphere. Had this happened, our own society might have been destroyed even if the Soviets had not been able to launch a single weapon.

If nuclear winter could creep up on us this way, what other surprises might be in store? The discovery of nuclear winter is an unanticipated development that means nuclear war would be even worse than we had feared. By the nature of things, the unexpected is more likely to fall on the negative side of the ledger. Nuclear winter was found on ground that had already been well ploughed by strategic theorists and planners. This failure of analysis is the sort of event that should lead us to question confident assertions that security might lie in the next technological breakthrough.

We should, for example, be skeptical of promises that a Star Wars defense will allow a move away from a strategy of mutual deterrence based on fear of annihilation. Star Wars, we are told, could make possible a strategy based on defensive systems. As desirable as this might be in principle, it is unlikely to work out in practice. In fact, by its nature, Star Wars would probably do more to create tensions than to reduce them.

Finally, I hope we will not be distracted by strategic snake oil. The belated discovery of nuclear winter would help us to realize at long last that the path to peace may be through arms control rather than through a never-ending succession of weapons systems disguised as bargaining chips.

[The prepared statement of Mr. Udall follows:]

UNITED STATES HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON NATURAL RESOURCES,
AGRICULTURAL RESEARCH AND ENVIRONMENT

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS
SUBCOMMITTEE ON ENERGY AND THE ENVIRONMENT

JOINT OVERSIGHT HEARING
ON
NUCLEAR WINTER

STATEMENT OF THE HON. MORRIS K. UDALL

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Some of today's witnesses will describe the nuclear winter phenomena. Others will tell us how they believe our strategic posture should be modified in light of it.

Before we begin, I want to say that it troubles me that we were nearly into the fifth decade of the nuclear era before our military planners explicitly accepted the potential destructiveness of the climatic effects of nuclear war. Such effects, it is now believed, could rival the damage resulting from the more familiar effects of blast, fire and fallout. It is worth reflecting upon the consequences of an attack by our Strategic Air Command upon the Soviet Union in the late fifties or early sixties. At that time, by all appearances, we possessed an overwhelming superiority; our military leaders had reason to assure the President that the United States could attack the Soviet Union and expect little or no retaliation.

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Finally I hope we will not be distracted by strategic snake oil. The belated discovery of nuclear winter should help us to realize, at long last, that the path to peace is through arms control rather than through a never ending succession of weapons systems disguised as bargaining chips.

Mr. UDALL. The gentleman from New York, Mr. Scheuer.

Mr. SCHEUER. Thank you very much, Mr. Chairman. I want to express my appreciation to you and your staff for the wonderful cooperation you have extended our staff in working out this joint hearing.

It is appropriate today that we have this joint hearing, inasmuch as today is the first day of serious discussions of nuclear countdown, nuclear strategy, that will be taking place in Geneva.

Under the nuclear winter theory that we are discussing, the fierce aftermath of a nuclear attack would send plumes of smoke, soot and dust from burning cities, industrial sites and forests lofting high into the atmosphere and, within weeks, these particles would cover the Northern Hemisphere and slowly drift into the Southern Hemisphere, blocking out most of the light and drastically reducing land temperatures. Under such conditions, survivors of a nuclear holocaust would face an extended darkness and freezing temperatures. Rivers and lakes would freeze over, plant life would wither and food production would be virtually eliminated in the ghoulish season of nuclear winter. The so-called victors of such a terminal battle would have little in the way of the spoils of victory as the effects of nuclear winter spilled over the far corners of the remnants of our Earth.

It is apparent that the implications of nuclear winter impose new realities on nuclear arms control strategy and nuclear deterrence. At the very least, the nuclear winter theory raises profound implications for the United States and, presumably, for our Soviet colleagues, too, imposing on all of us the necessity of new thinking, creative thinking, on issues such as nuclear weapons planning, procurement, deployment, targeting and command, as well for arms control and civil defense.

Much of today's hearing will focus on the recent Department of Defense report, "The Potential Effects of Nuclear War on Climate," which was requested by our distinguished colleague from Colorado, Tim Wirth, who is here with us today.

In my view, it is difficult to square the 17-page DOD report, with a mere 5 or 6 pages devoted to the policy implications of nuclear winter, with the statutory mandate imposed by our Congress on the Secretary of Defense to conduct a detailed review of the current scientific studies and I quote "A thorough evaluation of the implications of the theory and a discussion of the manner in which the results will be incorporated into nuclear weapons, arms control and civil defense policies." Nor are we assured by the level of resources committed by the Department of Defense to the study of this policy. Despite an overall weapons research and development budget of over $39 billion, the DOD requested a meager $2½ million, less than half of the amount that the President's own science advisor, George Keyworth, requested for this study.

Public debate on this issue must proceed from a careful scientific base and be guided by the best evidence available. Our intent is to air this evidence as openly as we can today. The issue of nuclear arms strategy and tactics and the impact that the theory that nuclear winter would have on that strategy is an issue which transcends all others in importance. Indeed, the fate of mankind rests in the balance, rests on our ability to cope with these incredible forces which man's ingenuity has unleashed.

[The prepared opening statement of Mr. Scheuer follows:]

NUCLEAR WINTER HEARING

STATEMENT OF HON. JAMES H. SCHEUER

March 14, 1985

Within a few years after the detonation of the first nuclear weapons, many of the architects of the atomic age began issuing apocalyptic predictions for the fate of mankind as a consequence of nuclear war. As Enrico Fermi warned--in 1949-- "the fact that no limits exist to the destructiveness of this weapon makes its very existence and the knowledge of its construction a danger to humanity." Over the last 35 years we have uncovered increasing evidence that a thermonuclear war of even medium scale could have catastrophic consequences for mankind. Today's hearing focuses upon the most frightening set of consequences yet discovered-- nuclear winter. It is believed that, quite apart from the devastating short-term effects due to explosions, intense heat and deadly radiation, an exchange of nuclear weapons could lead to frigid darkness, lasting months or even years, and threaten the very existence of survivors of a nuclear confrontation.

Under the nuclear winter theory, the fiery aftermath of a nuclear attack would send plumes of sooty smoke and dust from burning cities, industrial sites and forests lofting into the atmosphere. Within weeks, the soot and dust would cover the Northern Hemisphere and slowly drift over the Southern Hemisphere, blocking out most of the sunlight and drastically reducing land temperatures. Under such a condition, survivors of a nuclear holocaust would face extended darkness and freezing temperatures. Rivers and lakes would freeze over, plant life would wither and food production would be virtually eliminated in the ghoulish season of nuclear winter.

The survivors of nuclear war -- the so-called victors of such a terminal battle -- would have little in the way of spoils as the effects of nuclear winter spilled over the far corners of the remnants of our Earth.

Nuclear war could mean the end of our global societies as we know them today. Nuclear winter could mean the extinction of the entire human race and a large fraction of the Earth's animals, plants and microorganisms.

A short time ago, a number of critics charged that nuclear winter was too uncertain a phenomenon to merit serious study. In the last several months, however, a consensus appears to have formed regarding the validity of the nuclear winter theory. As the March 1 report of the Department of Defense recognizes, there is fairly general agreement ... that for major nuclear attacks the nuclear winter phenomena could occur as scientists such as our first witness -- Carl Sagan -- have predicted.

It would appear readily evident that the implications of nuclear winter impose new realities on nuclear arms control strategy and nuclear deterrence. At the very least, the theory raises profound implications for our -- and presumptively the

Soviets -- thinking on issues such as nuclear weapons planning, procurement, deployment, targeting and command, as well as for arms control and civil defense.

Much of today's hearing will focus on the recent Department of Defense report entitled, "The Potential Effects of Nuclear War on the Climate". In my view, it is difficult to square the 17 page DOD report with the statutory mandate that the Secretary conduct a "*detailed* review of the current scientific studies," "a *thorough* evaluation of the implications of the theory" and a discussion of the manner in which the results will be incorporated into nuclear weapons, arms control and civil defense policies. Nor, are we reassured by the level of resources committed to study this topic by the Department of Defense. Despite an overall weapons research and development budget of $39.3 *billion*, DOD only requested $2.5 *million* for nuclear winter research -- less than one-half of the amount requested by the President's science advisor, George Keyworth. It has been suggested by members of the White House "nuclear winter" panel that the amount of funding in the FY '86 budget will not allow us to advance significantly the level of knowledge of the climatic consequences of nuclear war. It is indeed ironic that while refusing to fund the research necessary to improve our knowledge base, the Defense Department decries the high degree of uncertainty that exists with respect to the atmospheric, environmental and biological consequences of nuclear war. I would caution to add, however, that we have convened today's hearing not to endorse a particular point-of-view or partisan stance on these issues, but to illuminate for the public and for the Congress what is clearly a set of important issues. We will hear from this country's foremost proponent of the nuclear winter theory and from representatives of the Department of Defense concerning their recent report. We will also hear a distinguished panel of experts discuss a range of views on the importance that the nuclear winter theory holds for our strategic planning. And from a final panel today, we will receive testimony on the recent study by the National Academy of Sciences, which addresses the level of uncertainty underlying the nuclear winter theory.

Let me say a final word about our purpose today in attempting to bring the issue of nuclear winter into the public's consciousness. In recent years, public debate on issues concerning nuclear deterrence and security has sharply increased. This is a healthy phenomenon, since all policy-makers--Democratic or Republican, East or West--should consider public views. At the same time, these public views, even on a subject as inherently depressing as the one which confronts us today, should not arise from ignorance and fear. As much as is possible, the public debate must proceed from a careful scientific basis and be guided by the best evidence available. Our intent today will be to air this evidence as openly as we can.

The issue of nuclear arms, and the accompanying theory of nuclear winter, is an issue that transcends all others in importance. The fate of all mankind rests in the balance.

Before I call on my colleagues, I would like to leave you with some succinct words from Winston Churchill -- "This revelation of the secrets of nature long mercifully withheld from man should arouse the most solemn reflections in the mind and conscience of every human being."

Mr. UDALL. Are there further opening statements? Mrs. Schneider?

Mrs. SCHNEIDER. I would like to commend my two colleagues and the two chairmen of the joint committees here for convening such a hearing. I think that there is very little question that the hearings that we are holding today are of profound importance.

I recognize also that in the public's minds there is a feeling that we are facing disaster at every turn and the calamity lurks behind every bush. This is very unfortunate because, far from crying wolf, the information that we are going to be receiving today is from scientists who represent a variety of disciplines on a topic that is as important as any that we are ever likely to face, the ecological consequences of nuclear war.

The report that has been released by the Pentagon on March 1, called "The Potential Effects of Nuclear War on the Climate," is an important addition to the awareness on the atmospheric side effects of nuclear war. But, unfortunately, this report does not add much to our understanding of those effects, nor to the development of a mechanism to further investigate this problem. I find it unfortunate that the report carried a tone of defending current policies. To state that it is not our policy to target population centers is of very little solace when the destruction of the world's ecosystem is a possible. Also, the strategic defense system would, in fact, discourage the Soviets from increasing their nuclear arsenals is a result of the report and, I think, also a result of delusional thinking. To suggest, as the report does, that fire effects could be reduced by detonating the bombs closer to the Earth and then, as a postscript, adding that such a tactic would be an increase in fallout, points out the critical need for understanding that a nuclear war would be totally unlike anything we have ever experienced on Earth.

Uncertainty is the hallmark of our understanding of the possible side effects of a nuclear war. In the last 40 years, we certainly had the opportunity to experience much with nuclear weapons. We've learned that we are capable of totally destroying cities, causing burning, mutilations of various victims and, when exploded in the atmosphere, that they produce radioactive fallout that can cause illnesses, large amounts of dangerous byproducts, including Strontium-90, could enter our food chain.

But I guess the worst news about the nuclear weapons that we are currently developing is what we don't know. We don't know how many explosions the planet can absorb before it is permanently altered. We also don't know how the ozone layer might be affected by high-level bursts. We also don't know what it means to win a nuclear war.

This examination of the potential for a nuclear winter needs to be expanded so that we can understand the lowest limits of irreversible damage to the ecosystem. It needs to be developed by a group that is independent, that has total and complete access to required information, and that is led by individuals who are courageous enough to follow the data wherever that may lead. We have a responsibility as Members of Congress to ensure that every policymaker in the world is aware of these findings.

Albert Einstein had said that the nuclear age would change everything—well, everything except the way we think. Certainly we have a continuation of the view of warfare that is as ancient as the practice itself: the more weapons, the better. Unfortunately, it will be exceedingly difficult to change that kind of thinking. Congress is constantly faced with the demands for additions to our nuclear arsenals, and the fact that we respond so readily is evidence of our failure to recognize that we have crossed an important threshold, one that demands a fundamental rethinking of the manner in which we provide for our defense.

Thank you, Mr. Chairman.

Mr. UDALL. The distinguished gentleman from New Mexico who is ranking Republican on our subcommittee is recognized for an opening statement.

Mr. LUJAN. Thank you, Mr. Chairman.

We in this country believe that the nuclear winter issue is of serious concern and should be studied. The Soviet Union is not taking the nuclear winter issue as seriously as the United States does.

There are some major questions about the nuclear winter scenario. It hypothesizes that half the world's arsenal of nuclear weapons would be detonated. Frankly, many people do not consider that to be a credible scenario. Has an analysis been done of other scenarios where less weapons are detonated? Do the results of such an analysis also produce a nuclear winter? Likewise, the nuclear winter scenario depends on the release of large amounts of smoke and dust into the atmosphere as a result of massive fires started by nuclear weapons effects. There is a wide range of variation on how much smoke and dust would be produced.

Clearly a key research need is to better refine the estimates of how much smoke and dust would actually be produced. This committee's jurisdiction is civilian R&D. We should look into whether the existing research efforts in climatic effects and fire, et cetera, are useful in analyzing the nuclear winter scenario. We should also consider whether the research efforts in studying the nuclear winter possibility will provide helpful insights into understanding natural phenomena of peacetime interests.

The nuclear winter issue should be taken seriously. We should ask what are the policy implications of the possibility of nuclear war. The most obvious one is that we should avoid a nuclear war. Since the possibility of nuclear war is being viewed with universal horror, it is hard to imagine that we need to have our resolve to avoid a nuclear war stengthened.

The second policy implication is that we should work toward arms reduction. Right now, the United States is meeting with the Russians in Geneva for that very purpose. Clearly we are proceeding along the proper lines. If indeed we reach agreement on arms reduction, it will only be meaningful to the extent that all parties comply with the agreement. The United States being an honorable country will clearly comply with any treaty on arms control. We need to verify that the Soviets would also comply. Therefore, we should ask whether or not the present technologies of verification are adequate, and also we should consider what additional research and verification technologies should be studied.

Finally, the nuclear winter scenario tells us that we need to think about other possibilities for defending our country that do not rely on nuclear weapons. Is the President's Strategic Defense Initiative the answer? Mr. Chairman, I will look forward to the answer to these and other questions during the hearing of the various witnesses.

Thank you.

Mr. Udall. The gentleman from Colorado, who has been a leader among those of us concerned on this issue.

Mr. Wirth. Thank you, Mr. Chairman. I want to thank you and Mr. Scheuer for such prompt response to the report that came from the Pentagon and having this hearing, I think now just 12 days later.

I would also like to associate myself in particular with the remarks of the gentlewoman from Rhode Island, who I thought was very, very clear and careful on this subject. Here we have the Pentagon effectively agreeing that the concept of nuclear winter is a valid concept, but the next step, what are the implications of that, appear to be ignored. What are the implications for the notion of first strike? What are the implications for the question of survivability? The Pentaton seems to say to us, even though we recognize that nuclear winter is a valid concept, the implications are that we should continue to do more of the same. It just doesn't seem to me to be a logical conclusion from the evidence that is available. That's why we're having this hearing today, to see if this logic holds up or if there are further implications for the Pentagon that they should be pursuing in response to the law passed by the Congress requiring them to look at this in great detail.

I look forward to this hearing. I again, gentlemen, thank you very much for putting this together.

[The prepared statement of Mr. Wirth follows:]

HOUSE OF REPRESENTATIVES
WASHINGTON, D.C. 20515

TIMOTHY E. WIRTH
2nd District, Colorado

Remarks of Rep. Timothy E. Wirth

U.S. House of Representatives

Subcommittee on Natural Resources, Agriculture Research and Environment

Subcommittee on Energy and the Environment

March 14, 1985

NUCLEAR WINTER

Mr. Chairmen, thank you for holding these hearings and giving me the opportunity to address the subject of nuclear winter. I believe that the importance of this subject is reflected by the very distinguished speakers we have before the subcommittee today, and I look forward to hearing their comments on this matter.

As we know, on March 1, the Defense Department released its report on the policy implications of nuclear winter. The report was compiled as a result of the amendment offered by Mr. Leach and I to the FY 1985 Department of Defense Authorization bill.

In looking over the report, I was pleased to see that DOD acknowledges the validity of nuclear winter. In its technical examination of nuclear winter, the Department concludes that the smoke and fire injected into the atmosphere by a nuclear exchange would have a noticeable effect on the global climate. The question that the DOD report raises is: what would be the magnitude of that effect?

The Pentagon claims that current scientific work does not give us any indication of the dimensions of the climatic catastrophe that would follow nuclear war. But its assertion in this regard is wholly unconvincing. To begin with, DOD focuses on only three research efforts that have been or are being undertaken concerning nuclear winter: the National Academy of Sciences (NAS) report, The Effects on the Atmosphere of a Major Nuclear Exchange; the study that brought the theory widespread publicity done by Richard Turco, Owen B. Toon, Thomas B. Ackerman, James B. Pollack and Dr. Sagan (known by the acronym TTAPS) and; DOD's own Interagency Research Program (IRP), which involves continuing work on nuclear winter by such agencies as NASA, NOAA, FEMA, and NSF.

While these sources are certainly important, DOD's examination of available scientific materials leaves much to be desired, and it is for this reason that DOD's sense of the magnitude of a nuclear winter is so uncertain. DOD complains that the TTAPS study is rudimentary, by climatic modeling standards. DOD also claims that the TTAPS study's estimates of smoke production, dust and smoke injection, and atmospheric ability to scavenge (rain-out) particles are overly pessimistic. As a result, while DOD admits that nuclear winter is a likely possibility, it also claims that the prospects of apocalyptic climatic catastrophe may be overplayed.

But DOD fails to note that the TTAPS report was issued in October 1983. Moreover, the Pentagon does not recognize that a significant amount of additional research on the TTAPS theory has taken place since that time. The National Center for Atmospheric Research in Boulder, Colorado, which is ably represented here by Dr. Schneider, has used advanced three dimensional computer-based climate models to examine the earth's atmosphere after a theoretical limited nuclear war. The results of the NCAR study, while not as dire as those in TTAPS, confirmed TTAPS' basic theory and would still likely mean the extinction of life in the northern hemisphere, and perhaps the world. And DOD has ignored the research of scientists working for the Lawrence Livermore Laboratory, which has basically confirmed the TTAPS scenario. These are just several examples of the long list of scientific works that directly or indirectly treat the problem of nuclear winter. DOD, in its follow-up studies of this important phenomenon, should take greater care to evaluate all available and relevant scientific materials.

Beyond ignoring important scientific research, the Pentagon also fails to acknowledge that it knows a critical variable that will determine the severity of a nuclear winter -- the number of urban targets in the war plans of the United States and perhaps of the Soviet Union. DOD is fully aware of America's plans for nuclear detonations over Soviet strategic targets, many of which are undoubtedly co-located with cities. DOD argues in its report that it would not threaten urban targets with large civilian populations because it "is neither a prudent nor a moral means of achieving deterrence." But it is well known that all versions of the Single Integrated Operational Plan (SIOP -- the Pentagon's targeting plan) have had as their basic objective the destruction of Soviet society. And in order to destroy a society, it is necessary to target those institutions that enable the society to cohere -- many of which are located in cities. Presuming that the Pentagon uses this assumption as its targeting premise, and given its expertise in devising SIOP's, it is also more than likely that DOD also has a good idea of the structure of the Soviets' target plan of the U.S.

One other point to make in this regard is that SIOP's have traditionally been based on the concept of overkill -- that is, each superpower has allocated to each strategic target substantially more nuclear warheads than are required to destroy the target with blast pressure. I might add, parenthetically, that the massive size of each superpower's nuclear arsenal is indicative of this emphasis on overkill. Hiroshima was completely destroyed by firestorms triggered by a 15 kiloton bomb. If we have targeted Soviet cities with multiple warheads of as much as, if not more than, one megaton (80 times larger than the Hiroshima bomb), is there any doubt that those cities will burn after nuclear attack? And is there any doubt that American cities and other strategic sites, similarly targeted and attacked, will be consumed by fire? Given the historical precedent of Hiroshima, our understanding of SIOP's and the destructive yield of modern nuclear weapons, is it really that difficult to project the severity of a nuclear winter? It is no wonder that the Pentagon was so hesitant about discussing the extent of the climatic catastrophe the earth will endure following a nuclear exchange.

The Pentagon's decision to downplay substantial scientific research, historical evidence, and knowledge of targeting plans as indicators of the potential severity of nuclear winter is disturbing. But even more disturbing, given DOD's willingness to accept the theory of nuclear winter, is its conclusion that this radically new vision of nuclear aftermath requires no adjustment whatsoever of our strategic nuclear policies. For example, DOD ignores the increased emphasis that nuclear winter places on issues relating to nuclear proliferation -- since climatic catastrophe can be triggered by even a small, strategically targeted arsenal, will this not force the superpowers to pay greater attention to the burgeoning number of emergent atomic powers, such as Iraq, Pakistan, South Africa and Argentina? What does this important implication mean for the scope and agenda of future arms control negotiations? The Pentagon has sidestepped this and other important issues and simply transformed the nuclear winter report into a platform from which to reaffirm its commitment to the President's Space Defense Initiative (SDI) and expanding the nation's nuclear arsenal.

Deterrence is the only strategic nuclear defense policy the Pentagon has ever known. It has been our nation's defense rationale for over three decades. And so, despite the very serious implications of the nuclear winter theory, the Pentagon has rather defiantly announced that nothing but deterrence, and then perhaps SDI, can protect the United States. Deterrence, supplemented by the slow, incremental process of arms control, will protect us, even though we have learned that a nuclear first strike by one superpower, even without the other's retaliation, may result in the destruction, by climatic and environmental means, of the aggressor, as well as the rest of the world. Deterrence will supposedly protect us, despite the fact that increased political tension or a computer malfunction may lead to a nuclear exchange that will spell the end of the human species. And, finally, we have been assured that deterrence will protect us, even though we have learned that the independent nuclear forces of France, Britain, China and eventually other nations may, if targeted correctly, be able to ignite enough urban fires to create a nuclear winter.

The Pentagon also assures us that even if a nuclear exchange is begun, we can mitigate the climatic effects through "escalation control." The report informs us that the current SIOP contains "a wide range of combinations of targeting and systems selection options." Is the

Pentagon telling us that this Administration is willing to resort to tactical nuclear warfare? Are we to believe that the Soviets would not respond to any nuclear attack with an equally limited attack? And how are we to know that the Pentagon has shaped these targeting strategies with environmental considerations in mind? The nuclear winter theory points out that even if a small portion of the superpowers' arsenals are used, there is a significant chance that climatic catastrophe can be triggered. In other words, tactical nuclear warfare also holds the potential for destroying our world.

The Strategic Defense Initiative also promises no panacea to eliminate the threat of nuclear winter. The Pentgon asserts that space-based anti-ballistic missile (ABM) weapons will be able to eliminate many Soviet warheads destined for the territories of our nation and our allies. But again, even though this may reduce the number of warheads hitting Western urban targets, this does not rule out the prospect of nuclear winter. Although scientists disagree on the feasibility of space defense in general, they are in agreement that such a defense would be far from seamless. Even scientific proponents of the SDI program have shifted their expectations from an invulnerable defense umbrella for population protection to a system that protects our missile silos and a few other strategic sites. We also have to look at the Soviet perspective on a possible space-based ABM deployment -- if they suspect an ABM deployment, what will hold them back from releasing their entire arsenal? Moreover, there is nothing to stop the Soviets from accelerating their production of ICBM's and warheads to increase the possibility of penetrating the ABM system.

The Pentagon also argues that SDI will enhance deterrence by undermining "the confidence of Soviet military planners in their ability to predict the outcome of an attack on our military forces." However, this implies that we will be basing our deterrent on uncertainty. As Soviet leaders become less able to verify our defense capabilities, at the same time we harbor large arsenals of offensive weapons, they are likely to fear a first strike and their inability to assure retaliatory destruction. History has taught us that conflict results more from uncertainty about an adversary's intentions than from any other factor. SDI injects a massive degree of uncertainty into what is already a less-than-certain relationship. If we begin to implement the results of the SDI research program, is there a greater likelihood that we are setting the stage for nuclear conflict and nuclear winter?

In its report, the Pentagon briefly alludes to another policy response to nuclear winter. It relates to changes in missile technology -- the production of lower-yield and increasingly accurate ballistic missiles, as well as missiles that may burrow beneath the target site before exploding (to minimize the combustion effects of the fireball). These technical alterations are important, but they do not go to the heart of the problem.

What is at the heart of this problem are the huge nuclear arsenals now in the possession of the U.S. and the Soviets. DOD itself recognizes that "the level of nuclear weapons which exists today is unacceptably high." Given that unacceptability, the U.S. needs to redouble its arms control efforts -- the talks in Geneva provide a perfect opportunity to negotiate the significant reductions in nuclear weapons that will ensure a world free of the spectre of nuclear winter.

The task of arms reduction is not simple. But it is far from impossible. Recently, I have spent a considerable amount of time discussing the issue of arms control with a delegation of high-ranking Soviet officials. They have expressed a deep and abiding concern about the threat of nuclear war to our world and future generations. Let us challenge them to match that concern with a negotiating position that will substantially reduce our arsenals. And at the same time, let us prepare to meet that position flexibly, with a view towards ensuring adequate defense and preserving the peace. Ultimately, Mr. Chairmen, we must challenge ourselves to recognize the horrible consequences of nuclear war, best represented by nuclear winter, and vigorously work, through negotiation, to prevent the realization of those consequences.

Mr. **Udall**. Are there further opening statements?

If not, we'll proceed with our first witness today, who is Dr. Carl Sagan of Cornell University, who has been in the forefront of the discussion on this important subject. Dr. Sagan, you are kind to be with us today, and we'll be glad to hear from you.

STATEMENT OF DR. CARL SAGAN, CORNELL UNIVERSITY, ITHACA, NY

Dr. **Sagan**. Thank you, Representative Udall. I'm very pleased to be here. Would somebody turn my microphone on. Thank you. I can do it myself, I see.

Some years ago when the first results of our study, the so-called TTAPS, study on nuclear winter, were becoming clear to those of us working on it—long before it was publicly released—it became clear to me that there were serious policy implications on the issue, not only the consequences in the Northern Hemisphere, but elsewhere in the world. The possibility which emerged clearly from our calculations was that something much smaller, Representative Lujan, than a full exchange would still lead to almost the same effect as the full exchange provided cities were targeted. In fact, one of our cases was a case where less than 1 percent of the world's strategic arsenals were employed but artificially constrained to be targeted on cities only, and there we got temperature declines of tens of degrees for months.

So being a novitiate in this strange subject, I felt the need to talk to more experienced people, and we were able to put together a private discussion, in fact, here in the Capitol, with a range of senior workers in this field, in previous administrations and other masters of dark arts. The distribution was very good. The most senior of the group who was there was Averell Harriman, in fact.

At the end I presented what the scientific results were, presented some hint of what seemed to me the policy implications, and one response by a senior practitioner was the following: He said, "Look, if you think that the mere prospect of the end of the world is enough to change thinking in Washington and Moscow, you clearly have not spent much time in those places." So by these standards, perhaps the Department of Defense report represents slight progress.

I see in the charge given by the Congress to the Department of Defense requests for "comprehensive study," requests for "detailed review," requests for "thorough evaluation," and I must say I do not see this report as coming within light years of that requirement. If this were a paper assigned in a graduate seminar at Cornell University, I think I would give it a D, maybe C minus if I was in a friendly mood.

For 40 years, the Department of Defense has, in effect, assured us that there are no long-term climatic consequences of nuclear war, that the climate is not in danger. There are reports by the Government through the years saying nothing to worry about. Then some scientists stumble upon a possible global climatic catastrophe, attendant, as I said, even to a relatively small nuclear war. At first, we hear that this is liberal propaganda or distortions invented by proponents of a nuclear freeze. Then there are other studies that tend to confirm the general picture. Then the National Academy of Sciences, the Royal Society of Canada, the Pontifical Academy of Sciences, the President of the United States, and eventually even the Department of Defense acknowledges that there might be something to worry about here. Nuclear winter, if it were brought about, would be a disaster unparalleled in the history of the human species.

And what is the Department of Defense's response? It's that, while nuclear winter might happen, there are significant uncertainties, of course, nothing is changed, that the correct answer to nuclear winter is to continue to build many more weapons systems in the aim of reducing weapons systems at some future, unspecified time. Peculiarly, nuclear winter turns out to justify all the policies that the administration has just embarked on. Remarkable coincidence. There are no agonizing reappraisals. There are no changes in doctrine or policy. From their point of view, the discovery of a doomsday machine hiding in the arsenals of the United States and the Soviet Union hardly matters at all. It doesn't change anything.

By comparison, let's compare this with the study released just 2 months earlier by the Royal Society of Canada, the equivalent of the National Academy of Sciences in our northern neighbor, which says, "We conclude that the nuclear winter hypothesis does indeed modify the global strategic position," and then they go on to indicate in what way, and I will mention a couple of things about that report in a moment.

Mr. Weinberger's 17-page report talks about the possibility that dangers from nuclear winter will be comparable to the other horrors of nuclear war. Well, how bad are those other horrors? According to a study by the World Health Organization, chaired by Nobel Laureate in Medicine, Sune Bergstrom of Sweden, as many as 1.1 billion people might be killed outright in a central exchange involving not just the United States and the Soviet Union, but Europe, China, and Japan, and another 1.1 billion people would die subsequently from the prompt effects if they did not receive immediate medical attention, which, of course, would be unavailable because the doctors in hospitals are by and large concentrated in the target zones. Well, 1.1 plus 1.1 equals 2.2. Two point two billion, according to this estimate—obviously nobody knows for sure, it might be more or it might be less—well that's roughly half the people on the planet, just a little less.

If, as the Department of Defense now acknowledges, the long-term effects—radioactive fallout, nuclear winter, and so on—might be comparable or even larger, then the Department of Defense now acknowledges that nuclear war might mean the extinction of the human species. In that sense, this represents an interesting departure for the Department of Defense. Certainly I would say nuclear war means the destruction of our global civilization, a nonincidental aspect of which would be the destruction of the United States as a functioning political entity. Nuclear war is bad for Government, bad for labor, bad for business, bad for people on a scale that remains unreflected, as far as I can see, in this administration's policies.

Now one significant consequence of nuclear winter is that nations far removed from the conflict, nations, if there are any, that have no part of the quarrel between the United States and the Soviet Union, nations in the Southern Hemisphere, might be utterly destroyed without a single nuclear weapon falling on their territories. It's a possibility. You will hear later from Dr. Schneider and others on recent work on involvement of equatorial and southern latitude regions.

The Royal Society of Canada says, "Nuclear winter globalizes the environmental impact of nuclear war." There is no hint of this in Mr. Weinberger's report. There is no reference to the Royal Society of Canada report.

There is also no reference to a report done by a branch of the Air Force, a branch with what I think is the best acronym in the business, CADRE, C-A-D-R-E, the Center for Aerospace Doctrine Research and Education, at Maxwell Air Force Base in Alabama. This report was prudently commissioned by the Office of the Secretary of Defense something like 1 year ago. Mr. Wagner doubtless will be able to tell us more details about that. I visited with them in the early days of their work. This is a bunch of majors and lieutenant colonels and some faculty members from the University of Alabama and Georgia Tech. They seem to me very good, very broad, very conservative. Well, they've produced a report; nobody seems to know where it is or what's in it. I understand it was published in January. What is in it? It would be most interesting to know what this branch of the Air Force that is designated to study the policy implications of nuclear winter has to say about it. It would also be interesting to know why is it that that report has not been released.

The military implications of nuclear winter seem to me to be very broad. For example, consider the question of battle management and damage assessment. There is a nuclear war. You have launched some warheads. You wish to see whether they have done what they're supposed to do. How do you find that out if the target zone is socked in with smoke and dust and fine debris? That is a narrow military consequence of nuclear winter. There's no hint in the Department of Defense's report that anything like that might be of interest to them, although doubtless it is.

And then there are additional ranges of questions from—how well do tanks function at −10 or −20 degrees centigrade, how well do air-breathing engines do in soot, all the way to the major strategic questions—for example, the credibility of the policy of extended deterrence against a Soviet conventional attack in Europe in the face of nuclear winter. Put baldly, would the United States risk nuclear winter at home in order to defend West Germany? That seems to me an issue worth thinking about. Are there implications for protracted wars? Do we have to envision submarines that sit in the abyssal depths for 6 or 9 months until the soot from the first minor exchange—if we could imagine nuclear war so limited—settles out so that we could then have the second round? It seems to me that even from the narrowest of perspectives of the Department of Defense, this report is inadequate.

The report does worry about what is generally called an asymmetry of perception. What if the United States is worried about nuclear winter and the Soviet Union is not worried about nuclear winter? Might there then be some strategic advantage that redounds to the Soviet Union because they are in this hypothesis too foolish to see what the consequences of nuclear war are? Should we also be too foolish to see what the consequences of nuclear war are?

It is a very curious question, and it has lots of good answers—for example, a major high-level joint study between the United States and the Soviet Union of the policy implications of nuclear winter. If the administration is worried about what the Soviets know and believe, there are means to find out, there are means to enlighten the Soviet Union on this issue if there are some deficiencies felt.

Now, asymmetry of perception is one thing, asymmetry of vulnerability is another. Is there a difference in the consequences for the United States and the Soviet Union if there were a global or even a northern midlatitude nuclear winter? Let me read three sentences from the Royal Society of Canada's report.

> The Soviet Union's sensitivity to small climate fluctuations is well known. Since 1972-1973, they have endured repeated drought-induced or frost-triggered crop losses on a staggering scale, mostly in the new lands opened up in the last two decades. The nuclear winter hypothesis predicts much larger stresses for the interior of Eurasia. A nation hard pressed to cope effectively with current natural climatic variability will face a vastly greater threat.

There is no hint of asymmetry of vulnerability in the Department of Defense report. There is nothing on implications for agriculture at all. Nothing on biological implications, except that they probably would be bad. Nothing on the functioning of society after a nuclear war as a consequence of nuclear winter.

Let me again just pull out the Royal Society of Canada's report. The Royal Society of Canada is a very small organization with very limited resources compared to those of the Department of Defense. Here, for example, Mr. Chairman, is a graph of how the area of Canada capable of growing mature wheat declines as there are temperature declines. So, with a 1-degree decline, it is all down there; with a 2-degree decline, there is hardly any place left in Canada where wheat can still grow. It would be very interesting to see this graph extended into the United States. What temperature declines are necessary to wipe out agriculture in the American Midwest? This is surely within the ability of the Department of Defense to do. No hint of any such study is shown here and, incidentally, in the greatly attenuated national plan for studying nuclear winter, there is no money at all allocated for biological, agricultural, social or other implications. It is all—and strategic implications. Everything is in the physics.

Now, it is to me remarkable that there is virtually nothing in this report about the implications of nuclear winter for the relations of the United States with other nations. And there have been within the last year some dozen prime ministers, other national leaders of various nations, most of whom are allied with or friendly to the United States, expressing grave concerns about whether nuclear winter has implications for those nations and their relations with the United States and the Soviet Union. And these proposed implications go all over the lot.

Some nations are concerned that nuclear winter makes them much more vulnerable, but other remarks—for example, one which, if I read it right, in the New York Times attributed to Prime Minister Papandreou of Greece who says if there's nuclear winter, then Greece will be destroyed anyway, never mind whether Soviet nuclear weapons fall on Greece, so, what the heck, we might as well have American military bases here. At least that is what it seemed to me the New York Times was saying—I may have misread it—an unexpected consequence.

Now on the question of funding for further research, I've indicated, first of all, the grave omissions in the plan that was encouraged by the President's Science Advisor, George Keyworth. As far as can tell, Mr. Keyworth did a very good job in recognizing the seriousness of the problem. Originally, this was supposed to be $50 million over 5 years. It now has been reduced to something like half of that. And there is an interesting question about how much of that is really new money and how much of that is simply relabeling money that has been already programmed to study areas of this sort.

Also, an important part of the administration's funding plan is how little money is given to the National Science Foundation which is, as far as I can tell, the sole source of support for university scientists, independent scientists, scientists not already working for the Department of Defense or the Department of Energy to study this. I am sure the administration does not wish to have its funding plan be misinterpreted, that the administration is afraid to sponsor further research on the subject by those who are not directly under their thumbs, university scientists especially. It is now subject to such a misinterpretation.

For 40 years, this administration, most of the principals in it, have been implacable foes of arms control. Now we are told—and this seems to be one of the principal conclusions of the Department of Defense's report—they say, in effect, give us a trillion dollars more or less for star wars and another trillion dollars more or less for offensive weapons, and trust us. We are dedicated to arms control.

The Department of Defense is full of people, I know from firsthand discussions, with grave misgivings about current strategic policies, current arms buildups, and star wars. I find it remarkable the DOD does not consider it its duty to present both sides of the argument. Congress does not hear from experts within the government who have grave doubts on these issues. Loyalty to the official doctrines of the moment is the paramount consideration. Whereas a free debate in which both sides are confident that, under those circumstances, the truth will out, that seems to me the prudent approach to issues of this magnitude and this difficulty and this seriousness.

Mr. Chairman, I have just a couple of concluding remarks. They are on star wars and the connection between star wars and nuclear winter. And I do this only because star wars seems to be the leitmotif of the report by Mr. Weinberger on nuclear winter.

First of all, everybody acknowledges that fully impermeable strategic defense systems are not in the cards, certainly not for the next few decades. I point out that a system which is between 90 percent and 99 percent impermeable, far in excess of what most sympathetic critics believe can be done, that such a system would permit enough Soviet warheads through an initial exchange to destroy the United States. So even after a trillion dollars, there is a very serious question of whether the United States could survive a nuclear war.

I also point out that if it is true that the destruction of a hundred cities, something like that, is enough to trigger nuclear winter, even a full-up star wars system might not be able to stop it and, if there were an exchange and the Soviets did not have their own strategic defense system, then American attacks on the Soviet Union alone would be sufficient to trigger nuclear winter, at least possibly.

The second point is that one of the major Soviet responses—they've already publicly announced that they would be driven in this direction if the United States appeared ready to go ahead with a serious strategic defense initiative—is for the Soviets to build more offensive nuclear weapons systems to saturate, to overwhelm the defense system. But that is the worst possible case for nuclear winter. What nuclear winter says is that there are too many nuclear warheads in the world. And for the response to nuclear winter to be a sequence of events which leads the Soviets to greatly increase their arsenals seems to me profoundly foolish. Star wars is a kind of Maginot Line in the sky, and it has all of the deficiencies of the standard Maginot Line, except that it is vastly more expensive and that it can lead to much graver consequences even than the Maginot Line mentality did.

Now the actual situation to bear in mind in a full exchange some decades from now with a star wars system is to imagine something like 10,000 nuclear warheads in the air from the United States toward the Soviet Union, in near space, surrounded by a cloud of something like a million decoys and penetration aids. Your job, should you choose to accept this assignment, is to pick out every one of the 10,000 warheads, ignore every one of the million penetration aids and decoys, and you have 10 minutes or less to shoot down all the warheads. If you miss a few percent, everybody is dead. That is your problem.

You're willing to bet your life on a battle management computer where the program is too difficult to be written by human beings. It has to be written by other computers. The program is too difficult to be debugged by human beings. It can only be debugged by other computers. The system cannot be tested at all, short of a nuclear war. And now the system can only be operated by a computer. No humans involved, except for the consequences. And if the system fails, the world is destroyed.

Now I submit to you that you have to be really looney tunes to bet the human race on this one. The only way to be really sure is to negotiate for major, dramatic, bilateral, verifiable cuts in the strategic arsenals.

Congresswoman Schneider quoted Albert Einstein, who said in 1945 that the advent of nuclear weapons had "changed everything except our way of thinking. And thus," he said, "we drift toward unparalleled catastrophe." That's what is most missing from this report, even a hint of a change in our way of thinking.

Thank you very much.

Mr. UDALL. Thank you, Dr. Sagan, for a provocative and interesting introduction to this important subject today.

We apparently have good attendance from both subcommittees, and I suppose we ought to operate under the 5-minute rule in fairness to everyone.

Mr. SCHEUER. Yes, indeed.

Mr. UDALL. All right. I'll defer to my colleagues and begin with the co-Chair of these hearings, the gentleman from New York, Mr. Scheuer. He's recognized for 5 minutes.

Mr. SCHEUER. Thank you, Mr. Chairman.

Dr. Sagan, you've given us a great deal to chew over, and the question is, where do we intervene? Where do we crank in this new factor of nuclear winter into existing arms control—arms control and strategy of all kinds?

The Defense Department does have some ameliorating limits on nuclear hits, for example. They have under the SIOP, the single integrated operational plan, they do have restraints—a criteria known as constraints on collateral damage. And that means that they will normally use the smallest weapon to take out whatever the target is, they won't engage in overkill on any one target. Now that seems to indicate at least a move in the right direction, that they are thinking of minimizing damage above and beyond what is necessary to take out a particular target.

Can you conceive of another criteria that would involve perhaps an urban—an urban fire, critical mass, which is what produces nuclear winter, that would take into account the number of weapons, kilotonnage of weapons, number of cities hit, the distance between cities, prevailing winds, temperature, time of year, and so forth, that would give the Defense Department some kind of maximum number of nuclear weapons, total kilotonnage, distribution, and so forth, that would provide a further limiting criteria—they've already established one, but this would be a further limiting criteria—addressed to the concept of nuclear winter, and addressed to the concept of avoiding whatever the threshold is, assuming there is a threshold and that we don't just move gradually by incremental steps into a darker and darker and darker period? Can you think of some way that, under this overall master plan that they call SIOP, such a factor could be introduced?

Dr. SAGAN. First of all, the United States is not the only—the only power that can trigger nuclear winter. So even if we were 100 percent convinced that the latest SIOP makes every effort under firm controls not to target populated areas, not to do all the things that would maximize nuclear winter, there is the question of the strategies of the Soviet Union, Britain, France, and China, all of whom, as far as we can tell, might have arsenals large enough to trigger nuclear winter. The last three mentioned, because of the nature of their arsenals, are primarily targeted on cities, almost entirely Soviet cities. So that's the first concern that I would raise about this issue.

Any solution to this problem that involves targeting raises questions of verification. How will the Soviets be able to believe us that we don't target Soviet cities? How will we be able to believe the Soviets that they don't target American cities? Will we have American military officers looking into the innards of the guidance system program of Soviet missiles? Will we allow Soviet officers to do the same for American missiles? It seems extremely unlikely and, therefore, bland assurances on the nature of the SIOP or the RISOP, the Soviet equivalent, simply don't carry much weight, it seems to me.

On the question of whether U.S. SIOP does or does not maximize nuclear winter, there are diversity of points of view. For example, Adm. Noel Gayler, the former deputy director of the joint strategic target planning Staff, the guys who do the targeting, said in testimony before the Joint Economic Committee—I can't remember, some months ago—that the colocation of strategic targets and cities and strategic targets and forests was so great that even an exchange which was designed only to hit strategic targets would burn cities.

And along those lines, the report by Mr. Weinberger that we were talking about has a very curious phrase. It says, "Our strategy consciously does not target population." Now maybe consciously means intentionally, or maybe consciously is intended to be counterpoised to unconsciously. It's very hard to understand how you could imagine a central exchange in which submarine ports are not targeted—they are in cities; in which secondary airfields distributed over the country are not targeted—they tend to be in cities; in which command and control facilities are not targeted—they tend to be in cities. Any thought of decapitation involves targeting cities. And it would be very interesting to hear a presentation on precisely how it is imagined that there would be a nuclear war at various levels in which cities are not targeted. Maybe there is such an explanation.

Mr. **Scheuer**. Isn't that sort of a semantical problem? It seems to me a little disingenuous for either our country or the Russians to say they don't target cities.

Dr. **Sagan**. I agree with you entirely.

Mr. **Scheuer**. What they do is target strategic targets——

Dr. **Sagan**. That's right.

Mr. **Scheuer** [continuing]. Industrial targets, government targets, and so forth, and they are generally located in cities.

Dr. **Sagan**. By accident.

Mr. **Scheuer**. By accident.

Dr. **Sagan**. Everybody is highly moral. Nobody intends to kill people, it just turns out that strategic targets kill people—that attacks on strategic targets kill people.

One final thing on that, Congressman Scheuer. I'm not sure to what extent Congress has oversight on SIOP, but it seems to me it's a clearly and properly a highly classified area. But it seems to me that, because the details of the targeting are now of general concern, that it would be useful for some selected Members of Congress, under the properly secure circumstances, to look into SIOP and see if what is alleged is, in fact, true.

Mr. **Scheuer**. I couldn't agree with you more on that. There seems to be an urgent need for a congressional oversight. We all have a top security clearance. But it seems to me that, at a minimum, the members of the Armed Services Committee, the Foreign Relations Committee and the Intelligence Committee should be briefed and should be involved not only in briefings, but in input, on just the kind of value judgments that we have been talking about—how do we factor in the concept of nuclear winter in our SIOP plan.

I thank you, Mr. Chairman.

Mr. **Udall**. The gentlewoman from Rhode Island.

Mrs. **Schneider**. Thank you, Mr. Chairman.

Dr. Sagan, I'm curious about which of the many uncertainties we ought to attack first. The Department of Defense recognizes the importance of improving our understanding of some of the technical underpinnings of the convincing hypothesis of a nuclear winter. And I'm just wondering to what degree is there some variation on the actual quantitative impact of a nuclear winter? The Lawrence Livermore National Laboratory has suggested that this concept may include—the whole concept of a nuclear winter could include a whole range of possibilities and not just an extended period of subfreezing weather, the fact that there would be fire storms and the heat would rise, thereby minimizing the freezing temperatures. How quantitative can we get in the predicting of this information, and should we seek further research into this area on the part of the Department of Defense or other Federal agencies?

Dr. **Sagan**. Nuclear winter is not a problem amenable to experimental verification, at least not more than once, and few of us wish to perform the experiment. It is, therefore, restricted necessarily to the best theoretical physics, the best computing programs and the best small simulations that can be managed. Every one of those, of course, should be vigorously pursued, and I am concerned that the level of funding that the administration, under restricted budgetary circumstances to be sure, has proposed is inadequate.

But at the same time—and by the way, other witnesses will provide their opinion on the degrees of uncertainty—Dr. Carrier, for example, who chaired the National Academy study. But at the same time, it seems to me it would be a grave error to say that we should not look into the biological, the societal, the strategic implications of nuclear winter until all the facts are in, because all the facts may never be in.

Here is a sentence from the Royal Society of Canada report on this very question. "At some point, the strategists have to accept the probability of the predicted consequences and incorporate that judgment into their thinking." Scientists tend to cloak their predictions in a shroud of ifs and buts. The Royal Society of Canada is not criticizing scientists, that is the nature of scientific work. But every aspect of the nuclear strategic issue is surrounded by uncertainties. We just talked about one. What are the Soviet SIOP's? What are the American SIOPs? What is the uncertainty of the Strategic Defense Initiative? What is the uncertainty of the gaps, the famous window of vulnerability? How uncertain was that? It drove the arms buildup partly that we are now in. I would like to see an even-handed concern about the reliability and verifiability of every aspect of this problem.

Mrs. **Schneider**. OK.

Let me also ask you, the Department of Defense report reviews some of the Soviet perceptions, and the conclusion that they reach is the Soviets have done very little work on this subject. Are you in agreement with that?

Dr. SAGAN. The Soviets, in my view, have not done nearly as much as they should and I hope will. It is, however, fair to say that the first three-dimensional general circulation model applied to this problem that gave results—or at least one of the first two—was a Soviet program. Admittedly, it was run on a computer with roughly the capability of an IBM PC, and with a program that ultimately comes from Oregon State University. But they at least did the study.

The Vice President of the Soviet Academy of Sciences, Dr. Velikov, told me that he has a budget of 2 million rubles for the next few years to work on this problem. It will be very interesting to see what the money is used for, if it is. But if we are to believe his statement at face value, the Soviet program is roughly of the same order of magnitude as the present U.S. program. But I think it is absolutely proper to raise public concerns about the level of the Soviet research effort in this area.

Mrs. SCHNEIDER. Have you been involved or had the opportunity to review some of the data that's being put together by other Federal agencies, such as, for example, NOAA, who is reviewing the climatic alterations and, to some degree, the biological impacts of a nuclear winter?

Dr. SAGAN. I was a consultant to the National Climate Office at NOAA that put together a plan to study nuclear winter. I was one of the reviewers of it. I thought it was, by and large, a very good plan, and I testified, I believe, before Mr. Scheuer's committee to that effect.

But it is greatly compromised by being restricted only to the physical effects—nothing about biology, nothing about society, nothing about policy, strategy and doctrine. [See appendix for NOAA plan.]

Mrs. SCHNEIDER. Who do you think in the Federal Government could best supply us with the societal analysis of the impact of a nuclear winter?

Dr. SAGAN. Good question. I had correspondence with Mr. Keyworth on this this issue. I believe that this, as many other aspects of the nuclear winter implications question, ought to be farmed out to universities, research institutes, and so on, and not restricted to the Federal Government.

Mrs. SCHNEIDER. Thank you very much.

Mr. UDALL. The gentleman from Colorado.

Mr. WIRTH. Thank you very much, Mr. Chairman.

Dr. Sagan, again thank you for your help.

When Congressman Leach and I initially proposed this amendment and it was passed by the Congress, it was our belief that this was an enormously important discovery, nuclear winter, and that the Pentagon should do two things. First, the Pentagon should come back to us and tell us if they believed that the concept of nuclear winter was valid; and second, if it was valid, what are the implications. On the first, they have come back to us and said, yes, it is valid. On the second, from your testimony—and I would suggest from my own reading—they have not come back to us and really told us what the implications of this might be.

Now you said that if this were a graduate paper at Cornell, you might generously give it a D. Other actions that you have would be either to throw the graduate student out of school———

Dr. **Sagan**. That's hard to do in this case.

Mr. **Wirth**. We can't do that with the Department of Defense, we can't throw them out, but we can do the other thing that you do and say go back and redo the paper.

Dr. **Sagan**. Right. You give them an incomplete. [Laughter.]

Mr. **Wirth**. Now it seems to me that we have the opportunity of giving them an incomplete. And one of the obligations that we have if, in fact, the concept of nuclear winter does have very broad implications for our targeting, for our arms control initiatives, for how we are developing our whole strategy toward the Soviet Union, then we should go back to them with a series of further questions, which we in the Congress clearly are capable of doing.

What would be the first three questions that you would go back to the Pentagon with? Assuming that they have agreed that nuclear winter is valid, they have done so, what then are the next three most important questions to face the Pentagon with?

Dr. **Sagan**. The first short-term question I would raise is, please provide immediately the report by CADRE on the policy and doctrinal implications of nuclear winter. I think that that would not involve going back and doing any more work. It is just that the Department of Defense left home part of the assignment.

Then, beyond that, I would—minus anything is that that report exists. It's locked up somewhere. So there isn't any rewriting necessary, it's just somebody has to reach into the drawer and hand it to the Congress. That ought to be done, it seems to me if Congress requested, in 24 hours after the request. That should surely be a significant first step.

Mr. **Wirth**. Mr. Chairman, if I might, I ask unanimous consent that we send a letter to the Pentagon requesting the CADRE report and have that, of course, expunged for the appropriate national security elements that might be in it. But it seems to me that if this report exists, we ought to request that and have that come to the Congress.

Mr. **Scheuer**. I would add the Palomar study also, Mr. Chairman.

Mr. **Udall**. Is there objection to a letter making that request?

Hearing none, so ordered.

[CADRE and Palomar reports are in the committee's files.]

Dr. **Sagan**. Then, beyond that, I would, since the meaning of the words "comprehensive study", "detailed review" and "thorough evaluation" seems to have been misunderstood by the Department of Defense, maybe a level of effort statement would be useful, namely, please provide Congress on a time scale of so many months a report which involves x hundred or x thousand man-hours of work on this. Then you can be sure that there will be at least a significant level of effort. This level of effort does not seem significant.

And the third thing that I would do is to request—I'm not clear who, but the administration—for a continuing study not just of the atmospheric physics and combustion and that physical science end of the problem, but also studies of the biological, sociological, and strategic implications of nuclear winter.

And certainly all of that is within the capability of this administration. If the Royal Society of Canada can do it, there's no question that the administration can do it.

Mr. WIRTH. Thank you, Mr. Chairman. I will take that advice back to the authors.

And again I might point out that this amendment was drafted not by a small, narrow group of people in the Congress, it grew out of a seminar that Congressman Gingrich and I had at which Dr. Teller and Dr. Sagan were the two principal speakers. Congressman Leach, Senator Cohen, and many others worked on the developing of the drafting of this language. So it was very carefully drafted, and clearly the response was not well understood, and I think we want to go back to that broad group of authors who were from all ideological, geographic, and other perspectives in the Congress who were concerned about this and thought it was important, and I think we want to give the Pentagon an incomplete and give them the opportunity to try again.

Thank you very much, Mr. Chairman.

Mr. UDALL. The gentleman from New Mexico, Mr. Lujan.

Mr. LUJAN. Thank you, Mr. Chairman.

Dr. Sagan, you correctly pointed out a grim scenario. We all certainly agree what would happen if thousands of weapons were exploded, regardless of where they were exploded. However, what concerns me is your direction, at least what you've said so far, is that we ought to do a lot of research in understanding the consequences of a nuclear winter.

I would be more practical. It seems like we should direct our efforts to avoiding the explosion of many, many weapons. The only things that I see that are being done are arms control, SDI to stop weapons from exploding, yet you criticize those two approaches. The President has said, and I would imagine that everybody agrees with him, that we should be at zero level weapons, that that should be the ultimate. Do you agree with him on that? I would imagine that you would. And if you don't, why not?

Dr. SAGAN. First off, I, by no means, opposed arms control. I'm all in favor of it.

Mr. LUJAN. But you say it's not practical because we cannot have verification.

Dr. SAGAN. No, no; that's what the administration says, that's not what I say. What I say is——

Mr. LUJAN. You just said that we couldn't have American generals——

Dr. SAGAN. We can't have verification of targeting.

Mr. LUJAN [continuing]. Looking at theirs and have Soviet generals looking at ours. How else are you going to verify?

Dr. SAGAN. By getting rid of the weapons.

Mr. LUJAN. How do you do that? That's what I want to find out.

Dr. SAGAN. Right.

Mr. LUJAN. How do you get rid of the weapons? That's, I guess——

Dr. **SAGAN**. It's like this, Congressman Lujan. Imagine here's a room. It's a bilateral facility operated by the United States and the Soviet Union.

Mr. **LUJAN**. But no such thing exists.

Dr. **SAGAN**. No, no; but this is a——

Mr. **LUJAN**. No; let's get—you know, I want practical answers. I want—I really do—my sincere desire is that there be no nuclear weapons on this Earth that can explode anywhere.

Now the situation is not that we have, you know, a joint agreement with the Soviets. The situation is that the Soviets have some, that we have some, that the British have some, and all the rest of them. What I want is some solution. What would you do if you had it in your power to say this is what we are going to do, looking at all of the circumstances as they exist, to avoid the nuclear weapon? What is the practical solution?

Dr. **SAGAN**. Thank you.

First of all, we recognize that the present situation is not the situation you have correctly longed for, so there has to be a change from the present circumstances. Otherwise, we will continue to be in a world with 18,000 strategic weapons and 55,000 total nuclear weapons, which is clearly foolish, foolish, criminally foolish.

What you do is to reduce the number of weapons. How do you reduce the number of weapons? First of all, bear in mind that the United States and the Soviet Union both have a vastly larger arsenal than is needed for any conceivable strategic deterrence. A single U.S. nuclear submarine can destroy between 160 and 192 Soviet cities.

Mr. **LUJAN**. OK, granted.

Dr. **SAGAN**. One U.S. submarine. We have 30 of them. And then we have silo ballistic, intercontinental ballistic missiles, and Strategic Air Command aircraft, and cruise missiles, and intermediate range ballistic missiles, and so on. And the Soviets have, with a somewhat different complexion of forces, some comparable destructive capability.

Now what is clear is that a tiny fraction of those forces on either side is enough to destroy the society of the adversary. That immediately suggests that there are vastly too many nuclear weapons in the world for any conceivable purpose except to bring about a kind of global suicide. Therefore, it is possible to make major reductions in armaments without in any way compromising the national security of the United States or the Soviet Union. In fact, it would enhance the national security of both of those countries. It is in the interest of both those countries to reduce their arms if they could believe the other—symmetric belief.

How do you do that? One thing you do is you send to negotiations with the Soviets people who are deeply committed to arms control and safe disarmament. You don't send people who have spent their lives arguing for the opposite.

A second thing you do is you start producing major studies with the Soviets on how you would go about doing this. The scheme I was about to mention to you a moment ago is the scheme of Admiral Gayler, who I referred to before, former Commander and Chief of all U.S. Forces in the Pacific, former Deputy Chief of Naval Operations for Research and Development, former Director of the National Security Agency. Admiral Gayler's plan involves a bilateral facility to which are delivered not nuclear weapons, but the fission triggers of nuclear weapons, the little atomic bombs which explode the hydrogen bombs. You can verify that the fissionable material is in the fission triggers as delivered very easily. In his scheme, the fission triggers are, in fact, then redelivered to nuclear powerplants and converted into electricity, the ultimate in beating swords into plowshares.

There are many other schemes, but just imagine that one. Every day, the United States and the Soviet Union delivers some warheads, obviously the ones they need least, and they start cutting into the enormous bloated unnecessary arsenals. Eventually the day comes when they start cutting into the meat. That will be a day far into the future. You have to worry about can you make a path which does not compromise the security of the United States or, for that matter, the Soviet Union. Many knowledgeable observers believe that there is such a way to do that.

Now the question you've raised about can you get down to zero is an important question. Perhaps Secretary Perle would wish to comment on it. The prevailing wisdom is that getting down to a small number can be done relatively easily—safely, not easily—but getting down to zero is tough because of the possibility of sequestered nuclear weapons by one of the major powers or by some other player in this game.

Mr. UDALL. The gentleman's time has expired.

Mr. LUJAN. Thank you.

Mr. UDALL. The gentleman from Lousiana, Mr. Huckaby.

Mr. HUCKABY. Thank you, Mr. Chairman.

Dr. Sagan, it appears to me that the discovery of this phenomena of nuclear winter is perhaps the most important discovery that will be made in the last half of this twentieth century. I would suggest that it's possible for the scientific communities, both in the United States and Russia, to arrive at a consensus—and certainly that consensus doesn't exist today. I attended the debate between you and Dr. Teller that Mr. Wirth referred to.

My question is, do you think it's scientifically possible through computer modeling, et cetera, for at some point in time a consensus to evolve, a strong consensus, among the scientific community, both in the United States and Russia, of the phenomena of nuclear winter so that both the leaders, political leaders, the scientific leaders, as well as the people of both countries, could clearly recognize that there can be no winners, that no side would come out significantly better than the other?

You referred to the possibility of a high-level joint study in your testimony. Would something of this type, could it lead to this type of development and, if so, in what timeframe, in the timeframe to have any impact at the talks at Geneva?

Dr. SAGAN. Well, first of all, the idea—certainly what has been happening is that increasing numbers of competent scientists in relevant disciplines have been saying over the last year or two that nuclear winter looks serious or, as the National Research Council put it, it is a "clear possibility." I don't think there will ever be a 100-percent consensus on this issue, in part because nuclear winter has, as I have been attempting to indicate, policy implications which are at variance with the conventional wisdom.

It's very hard. it is tremendously hard, to reverse field after 40 years in which Presidents and Members of Congress of both parties and Soviet leaders have all tacitly agreed that more weapons makes you safer. It's very hard to reverse field.

I recognize that the President's strategic defense initiative is an attempt to treat that concern. The idea of a policy of mutually assured destruction is, of course, loathsome. The Catholic bishops made that point in their report. But it's not a strategy, it's a fact of life. It is simply the way we have arranged things. And, unfortunately, the strategic defense initiative is tremendously flawed, but I believe that somewhere at the core of it, there is a generous impulse.

But as far as what can be done on a short timescale, as you ask, there's an enormous amount that can be done, but it involves who are the negotiators representing the United States, and how dedicated are they to actually achieving agreements. I mean, the situation in Geneva is very clear. The Soviets say that an agreement on no weapons in space is the key, and the United States says an agreement on no weapons in space is precisely what will not happen. Now that is starting out at loggerheads at the very beginning. So I do not think there is very high likelihood of dramatic news coming out of Geneva. Again, it would be interesting to hear Secretary Perle's view of that matter.

But the issue of joint studies, of high-level discussions on this issue could be implemented tomorrow with one phone call from the Executive Office. So there's no question that something of that sort could be done swiftly if there were the political will to do it.

And I stress that the President has, in a way, endorsed nuclear winter in an interview in the New York Times a few weeks ago. He said that if a volcano can go off in Indonesia and produce a year without a summer a year later in New England, then imagine what the consequences of blowing up the entire nuclear arsenals are, and it's a proper comparison.

Mr. HUCKABY. Thank you, Dr. Sagan.

Mr. UDALL. The gentlewoman from Kansas, Mrs. Meyers.

Mrs. MEYERS. Dr. Sagan, are you inferring that the CADRE study just has not been released or that—what are you saying to us about that study?

Dr. SAGAN. That depends on what's in it. For all I know, it has things in it highly favorable to the administration's point of view, in which case it's hard to understand why it hasn't been released. On the other hand, it's possible that it has policy implications in it which are at variance with the administration's point of view and, in which case, it might be easier to understand why it hasn't been released. This is a matter of speculation. It depends on what's in it.

Mrs. MEYERS. It's extremely important, I think, that we do all really understand as much as we can about the disastrous effects of nuclear winter, nuclear war in general. But it's even more important, maybe, that we communicate this to the American people so that it's translated into political pressure to do something about it.

Do you know if the Soviets and the British and the French and the Chinese are also trying to understand sufficiently what the outcome would be, and are they trying to communicate to their populations?

Dr. SAGAN. I can tell you something about the Soviet situation in this regard. And let me try to indicate the uncertainty of my information as I explain it to you.

There have been major—but I would not say massive—discussions of nuclear winter in Soviet press, radio, and television. There have been articles in Izvestia and Pravda. There has been a television rebroadcast of a satellite link between American and Soviet scientists in Washington in November of 1983 discussing the nuclear winter issue, and that was shown on All-Union television in the Soviet Union.

What I just told you I have independently—that is, I have reports of Americans who were in Moscow, who saw the television programs. I have the clippings from the Soviet press, so that I am quite sure of. What I am now to tell you I am not firsthand sure of. Dr. Velikov, who I referred to before, the vice president of the Soviet Academy, told me at a meeting in the Vatican a little over a year ago—where I briefed the Pope on nuclear winter—he told me that he personally had given extensive briefings on nuclear winter to then Defense Minister Ustinov and to Foreign Minister Gromyko. I was unable to tell him in return that Secretary of State Shultz received comparable briefings. Perhaps they have, but not as far as I know by anybody who is actually working on the subject. So to that extent, there has been at least some permeation of the understanding of nuclear winter to the Soviet public and to the Soviet leadership.

In the case of China, it is clear that it is just now beginning to enter into official thinking. In China, I don't know of any evidence that it has appeared in the Chinese press. Perhaps it has, but I don't know about that.

I believe there is a study ongoing within the defense establishment of Great Britain on nuclear winter.

I do not know what the situation is in France, except that I did talk to President Mitterand about it, and his response was that I need not worry about a misuse of the French Force de Frappe, that it was in good hands.

So that's a quick summary of the situation. Information on nuclear winter is percolating throughout the world, but at a slow rate.

Mr. UDALL. Mr. Markey.

Mr. MARKEY. Thank you, Mr. Chairman.

Dr. Sagan, I am a dedicated student of the obvious, and what I'm wondering is why did it take so long to discover that where there's fire there's smoke? It is only something which has become apparent in the past 3 years or so that, in fact, there is a relationship between these fire storms on earth and ultimate consequence in the atmosphere. Why the time gap between the creation of the weapon and the consequence?

Dr. SAGAN. I wish I knew the answer to that one, Congressman Markey.

First of all, I wish we had done the study much earlier. We could have. In the middle seventies, we were worrying about the climatic consequences of volcanic explosions on the earth and, at least for the dust component of the problem, we were pretty much set up then to do it. We just didn't get around to it.

Why the Department of Defense, which has a statutory requirement to inform the President of what the consequences of nuclear war are, why the Department of Defense did not do a serious study of this 20 years ago, 30 years ago is another interesting question. It probably has to do with compartmentalization of function and the question of who is it who is responsible for looking at the adverse possibilities, the ones which would be embarrassing to a nation with tens of thousands of nuclear weapons.

Mr. **Markey**. I agree with Congressman Lujan and you, and I think everyone in this room, that arms control is a vital component to world security, not just to reduce the number of nuclear weapons, but also to make the use less likely, which is why it is disturbing that many of us believe that arms control is now being used as a bargaining chip to get new weapons rather than to reduce the number of already existing weapons.

I wonder if you could comment on the position that the Pentagon has which claims that star wars limits the possibility of nuclear winter, but they haven't told us how star wars would be affected by nuclear winter. Can their satellites receive information when the atmosphere is clouded with smoke? They claim that their strategic buildup is still necessary, but they don't address the issue of whether or not their air-breathing delivery systems can fly through a smoke-filled atmosphere. Could you address that question?

Dr. **Sagan**. There's that question—there are a number of questions that I don't claim to have any answers on, Congressman Markey. I've not studied the question of how an atmosphere loaded with fine opaque particles would interact with the various weapons systems that are components of the so-called strategic defense initiative. That's certainly a study which should be done.

Mr. **Markey**. If you could also comment on the two other aspects of the study which bother me considerably. One is that they claim that the Soviets—that is, our Government claims that the Soviets have not been cooperative and that they use the theory only for propaganda, that is the theory of nuclear winter. But a State Department memo of March 1984 states that the Soviets are also making some interest in conducting nuclear winter research under the U.S./U.S.S.R. environmental exchange agreement. For example, in recent discussions with—and I am now quoting from the State Department—"For example, in recent discussions with the U.S. scientists, the Soviets proposed setting a large-scale forest fire in Siberia and using U.S. equipment to study the effects, sharing the results with the U.S. scientists." That sounds like cooperation, to me anyway.

But what bothers me even more is that the memo goes on to say that, "The administration is not considering such cooperation. In any event, some may believe it politically difficult for the United States to engage in such an experiment under the environmental exchange agreement since nuclear freeze advocates are so closely linked with the nuclear winter advocates." Now that bothers me because it appears that they are making a decision as to whether or not a scientific study should be conducted on the basis of which part of the political spectrum in this country is advocating that it is necessary.

Dr. SAGAN. Right, ideological tests for the ability to pursue science.

Mr. MARKEY. And that is, in fact, hindering our efforts and our country's efforts in gaining the information which will make it possible for us to make intelligent decisions..

Dr. SAGAN. I would like to see the government embrace the principle that the truth is what we're after and let the ideological chips fall where they may and let us really look at every aspect of nuclear winter and see what comes out, and not be afraid of who is doing the study.

Mr. MARKEY. I think there is no question of what they've done is treat a scientific issue in a purely political fashion, and that is going to have very dangerous consequences for this country and this planet.

Thank you, Mr. Chairman.

Mr. UDALL. We're anxious to get to Secretary Perle. I think we have one more panel member who has not been heard for questions here. Mr. McCain.

Mr. MCCAIN. Thank you, Mr. Chairman. As you requested, I'll be very brief.

Doctor, I believe that most Americans before you who have been involved in this fantastic exercise of yours were totally aware of the terrible and horrific consequences of a nuclear exchange.

Since we are giving grades for the DOD, I would have to tell you, sir, that in response to Mr. Lujan's question as to how we can reduce nuclear weapons, I would have to give you an F. I would also tell you of my resentment of your statements concerning the desires and commitment of our President to arms control. I also happen to know Mr. Kampelman, Senator Tower, and other members of the negotiating team extremely well, and many of us resent your statement concerning their commitment to arms control as well. Particularly at the time that these talks are just beginning, it serves no useful purpose to cast aspersions on their dedication to arms control, which I believe are just as sincere and dedicated as yours are and the people who support your cause.

Finally, I guess I might have one question, and that is, if we are unable to achieve meaningful negotiations with the Soviet Union, would you then advocate unilateral reduction of arms on the part of the United States?

Dr. SAGAN. To answer the first part of your statement, let me ask you, can you name a single——

Mr. MCCAIN. You're hear to answer the questions, Doctor.

Dr. SAGAN. This is a method of answering. This is called a rhetorical question.

Mr. MCCAIN. I see, which has been the subject of most of your statements.

Dr. SAGAN. Can you name a single arms control agreement that Mr. Reagan has been for? Has he been for the ABM treaty? Has he been for the limited test ban treaty? Has he been for the outer space treaty? Can you name any of the treaties which are in force—the limited test ban treaty protects, for example, mother's milk from contamination by Strontium-90. Can you name any of those that Mr. Reagan has been in favor of?

As far as I know, he has opposed every one of them, and this——

Mr. McCain. This administration is observing SALT II, as you know.

Dr. Sagan. That's not my question.

And as far as I can tell, there is a dedicated opposition to arms control.

Mr. McCain. I think you are missing the point, Doctor.

Dr. Sagan. If I'm mistaken, I would love to see a historical record. I'm not criticizing the President, I'm merely making a statement of what I believe is fact.

Mr. McCain. I believe you're badly misinformed then.

Dr. Sagan. Please tell me which treaties he has supported.

Mr. Udall. I'm not sure this is the right forum in which to answer all of these questions.

Mr. McCain. I request no more time.

Mr. Udall. Thank you, Dr. Sagan, for being with us today.

Dr. Sagan. Thank you very much, Congressman Udall.

Mr. Udall. We will now hear from Secretary Perle, who has kindly consented to be with us today.

I think, Secretary Perle, that a poll of informed people in the Washington area would certainly get agreement that you're one of the two or three most influential people on these questions that these joint subcommittees are considering. So I am particularly grateful at this critical time that you would come here and give us the benefit of your thinking. We would be glad to hear from you in whatever way you think would best help put across your point of view.

STATEMENT OF RICHARD N. PERLE, ASSISTANT SECRETARY OF DEFENSE FOR INTERNATIONAL SECURITY POLICY, U.S. DEPARTMENT OF DEFENSE, ACCOMPANIED BY RICHARD L. WAGNER, ASSISTANT TO THE SECRETARY OF DEFENSE FOR ATOMIC ENERGY, U.S. DEPARTMENT OF DEFENSE

Mr. Perle. Thank you very much, Mr. Chairman, for the invitation to participate in this hearing.

I must say I'm a little disappointed at what I've heard thus far. I came to this hearing never having met Dr. Sagan before, but aware of his reputation as a scientist, expecting that he might enlighten this committee and those of us from the Defense Department who came to hear him about the phenomenon of nuclear winter, about efforts to narrow the uncertainties that he knows well exist about the parameters associated with that phenomenon, in short, about the science on which he's expert.

I didn't hear a word of science this morning. I heard a shallow, demagogic, rambling policy pronouncement. Not only would I give it an F if it were a policy paper in the bureaucracy, I wouldn't keep a GS-13 whose recommendations in the face of what he believes to be and what we share in our belief is a serious problem. The recommendations are so shallow and, in some cases, absurd as to leave one aghast at what words transpired since the discovery of this phenomenon by Dr. Sagan.

The idea that the solution to this problem lies in putting Russians and Americans in a room where they will receive nuclear components, the idea that this is to be taken seriously as a solution to the problems posed by the phenomenon of nuclear winter leaves me practically speechless.

Mr. Chairman, I think one of the reasons for the confusion this morning is that there has been behind practically all of the remarks this morning from both the witness and a number of members of the committee the presumption that it is inevitable that, because of the nuclear winter phenomenon, there must follow changes in American strategic doctrine and policy. The presumption, I say because there hasn't been a shred of evidence introduced to the effect that our current doctrine and our current policies are not better suited to deterring the war that we are all trying to prevent, or mitigating its consequences if it should occur, than any other policy that's been put in its place.

And while Dr. Sagan, when pressed in a question put to him, refused clearly to say that we are to make unilateral reductions, I think it was entirely clear from the thrust of his remarks that the only logical consequence that can flow from his view of the world is that we ought to make unilateral reductions because, if we ever use the weapons that he thinks we might use, we would bring about nuclear winter and international suicide and, for that reason, it would make perfect good sense unilaterally to reduce those weapons. I only wish he had had the courage to see his logical structure through to a logical conclusion.

Now this administration accepts the proposition that there are levels of nuclear weapons exchange at which the phenomena described in the nuclear winter studies would occur with devastating consequences. But we recognize, and would hope that others would recognize, that there is a significant range of uncertainty as to precisely how many weapons under precisely what circumstances would produce precisely what climatic changes. We think it's important to continue to do work in order to refine those estimates and those judgments, but the range of uncertainty is very sizable indeed. And it does not, in my judgment, advance our scientific understanding when loose statements are made that attribute a degree of certainty we do not have the privilege of now possessing, to the levels at which different climatic effects would occur. When Dr. Sagan says, as he has in the past, that 100 weapons on 100 cities would be enough to produce nuclear winter, that suggests a degree of certitude that he cannot possess, because we, the scientific community, do not possess it.

We have a Research Program aimed at refining the judgments that go into understanding the phenomena involved. It's a sensible Research Program. I think there was regret expressed this morning that we had put $2.5 million rather than the $5 million recommended into it. I think there's a misunderstanding there. The total Government funding is on the order of $5 million. The Defense Department contribution is roughly half of that to a broader administration effort.

Now what are the implications, granting that there is some level of nuclear exchange at which the phenomena described as nuclear winter would occur, for American policy, for our security, for world peace, for our survival, and not least of all for our freedom and independence?

The first implication that we would draw is that we had better assure the effectiveness of our deterrent force because, whether we like it or not, the best hope we have of preventing nuclear winter, and the other consequences short of nuclear winter that would nevertheless be devastating beyond belief, is to deter that war from ever taking place. And the policy of this administration and previous administrations is aimed at doing precisely that. And the programs of this administration are not different in significant respects from the programs of previous administrations. Virtually the whole of the Reagan Strategic Modernization Program, for example, has its roots in the plans and programs of previous administrations. So, first, we need to assure the effectiveness of our deterrent forces.

Second, I believe we need to reduce the number of nuclear weapons in the world and, in this, I agree with Dr. Sagan. I think, as he put it, there are too many nuclear warheads in the world. But let's recognize, first of all, that the United States has, in fact, been reducing the number of nuclear warheads in the world. We have 8,000 fewer nuclear weapons today than we had in 1967. You didn't hear that from Dr. Sagan, nor did you hear him reflect on the fact that the Soviets have added more weapons than we have reduced in this same time period. So while there are indeed too many nuclear weapons in the world today, one important reason for that is that the Soviet increases have outpaced the American reductions. And not only do we have 8,000 fewer nuclear weapons today than we had in 1967, we have reduced the megatonnage of those weapons to a bare 25 percent of what it was in the 1960's. That, I believe, is the right direction for us to move in, in the hope that we will eventually get to levels where the nuclear winter phenomenon will not be a concern. I think we all agree on that.

And there is no point starting a discussion on this issue with demagogic attacks on the sincerity of the administration when it comes to arms control, because the reductions I have just referred to, Mr. Chairman, came about not as a result of arms control agreements that permitted massive increases.

And the answer to Dr. Sagan about what treaties the President supports is that none of the treaties he refers to have had the consequences he thinks they might have of reducing weapons. The reductions I referred to were unilateral reductions undertaken on the part of the United States in the best interests of developing, procuring, and deploying a sensible deterrent as we see it.

And the arms control process to which I have heard again and again this morning, the most sublime homage paid, has failed to achieve the kinds of reductions that we have introduced unilaterally. And there is no sense kidding ourselves. This is a serious problem, it deserves a serious solution, and we ought to examine the history of arms control to see how effective it has been in bringing about reductions in the number of nuclear weapons in the world.

I participated for a couple of years in chairing a committee of the North Atlantic Alliance that, a little over a year ago, recommended the United States reduce by an additional 1,400 the number of its nuclear weapons deployed in Europe, and we are now undertaking that reduction. And the committee deliberately decided that we would not approach the Soviet Union with a view to an arms control negotiation over reductions in those weapons because we know that the moment we introduced that issue into arms control negotiations, it would be years, if ever, before the reductions actually took place.

So I must say I am a little bit tired of hearing, as a last retreat in the absence of any concrete advice commensurate with the concern expressed, that the administration has sent to Geneva people who are not serious about arms control. The people who were serious about arms control, whose seriousness is never questioned—Mr. Warnke, for example, from the previous administration, or Gerard Smith from an administration before that—brought us treaties that have today produced thousands and thousands of additional weapons beyond the weapons that were in the possession of the Soviet Union on the day those agreements were signed.

Now in order to achieve the kind of significant reductions beyond those that we are able to undertake safely and unilaterally, we need, in my view, a significant arms control regime. But how do we get it? We don't get it by putting a couple of people in a room, a proposal that assumes that the agreement has already been reached that we are going to bring about reductions.

This administration—and Dr. Sagan knows it, and if he doesn't know it, it's because he hasn't bothered to look—has proposed deep reductions in strategic offensive nuclear forces, the very forces that he believes could create a nuclear winter. This administration has proposed the total elimination of intermediate nuclear forces. And we've made both of these proposals and sustained them over the last 2½ or 3 years in Geneva. We've kept these proposals alive, even in the face of the Soviet walkout from Geneva. And I frankly think it is outrageous that, given the unwillingness of the Soviet Union to respond positively to our proposals for reductions, we should stand accused of not sending people to Geneva who are serious about negotiating arms control.

Now in addition to continuing the effort, and we will continue that effort—by every means we know how, we will try to persuade the Soviet Union that reductions are in their interest as well as ours—we need also to pay close attention to the strategic doctrine that we employ and the way we target our weapons. And the fact is that our strategic integrated operational plan calls for the ability of the President to withhold weapons from the cities of the Soviet Union, not because of the nuclear winter phenomenon, but because we have no desire to inflict millions of casualties on innocent men, women and children.

And let me say that absent in the whole of this hearing until now has been any recognition that the Department of Defense, which has been chastised for not discovering nuclear winter and for not embracing it with the same grandiose rhetoric as the administration's critics, the Department of Defense has understood for a very long time what an immense tragedy a nuclear war would be with or without nuclear winter. The idea that our policy should be fundamentally different because, instead of the destruction of hundreds of millions of people through prompt and immediate effects of a nuclear war, that our policy should be fundamentally different because we now realize that the consequences are even worse than was realized before, misses the fundamental point. We are serious about avoiding a nuclear war because the consequences that we have known about before the discovery of nuclear winter are persuasive enough reasons for avoiding a nuclear war by any means that men of good will can devise to do that.

Now the issue has been raised about the Soviet interest in nuclear winter. And I was sorry that Dr. Sagan didn't comment, because I think he's probably in a position to do so, about how our scientific community has been struck by the difference between scientific views expressed by the Soviets in private and those that they express in public which are—it will come as no surprise—the party line, whatever the party line happens to be. It poses a real problem for serious scientific cooperation with the Soviet Union when we know that their scientists say to us that they hold views that they are unable to express, because the only view they are able to express is the approved political view. And I sat here and listened to a Member of the U.S. Congress say to us that the Department of Defense is playing politics with a scientific issue.

Now what Mr. Markey didn't know was that the memorandum he had seen, was referring to, was a conversation between a State Department official and a deputy of the Soviet Academy of Sciences, in which the proposal to which he referred was made and it was subsequently withdrawn. And I have grave doubts about whether it was ever made with sincerity in the first instance.

Now let me say a little bit about the strategic defense initiative on which Dr. Sagan is also an expert. What this administration has proposed to do is conduct a 5-year program of experimentation to see, to find out, whether the development of technologies largely in the civilian sector that could bear on the development of a strategic defense have put the United States in a position where we might be able—where we might be able—to develop a reliable system of strategic defenses. We don't know whether it's going to prove possible or not. We know the Soviet Union is working hard on the development of such a system, has been doing so for years with increasing vigor following the ABM Treaty of 1972, and I think we ought to be smart enough to know that if we abandon our program in a manner that couldn't possibly be verified by arms control, the Soviets will carry on with their program just as they have carried on with a number of programs in violation of the existing treaties between us.

Is Dr. Sagan suggesting that we abandon our research program? Is he so sure of the unworkability of a strategic defense that he can now declare before the research is done that it's not possible? I think the only sensible reaction to the situation in which we find ourselves, with massively growing Soviet offensive nuclear forces, with no certainty that we will achieve an arms control agreement that provides for significant reductions, and with a significant Soviet SDI research program on the way, is to conduct an SDI research program of our own. And if we should prove to be successful, would Dr. Sagan not prefer that that strategic defense intercept the warheads that would produce the nuclear winter if they detonated on the surface of the earth?

Dr. Sagan has urged when pressed for recommendations that his first recommendation is that the Congress should be given a report prepared by the Air Force. Now either Dr. Sagan has seen that report and is prepared to speak for its wisdom and validity, or it seems to me he squandered his opportunity to give this committee advice by proposing as his first order of priority that you be given a report that he hasn't seen. I rather suspect that he's seen it. And I am advised by my colleagues that it is a political science paper, does not bear on the science of nuclear winter—which is what I think this committee was interested in, and properly so—and, like a lot of papers, we think it isn't a very high quality piece of work. Dr. Sagan is free to disagree with that, but I wish he'd introduce the arguments from that paper that he finds appealing and not attempt to turn this issue into a false issue of the administration somehow concealing some brilliant piece of work which, if only it came to light, would produce immediate changes in administration policy.

Mr. Chairman, I think I've talked long enough. I hope that there will be some questions from the committee. I hope in particular that we can focus our time on why it should be assumed that the phenomenon of nuclear winter automatically requires that the administration change the strategic doctrine and policy of the United States, because I say to you that our policy and doctrine is aimed at preventing a nuclear war, and the potential of a nuclear winter is an even more powerful reason for preventing a nuclear war. And it is by no means obvious to me, as it evidently was to Dr. Sagan, that the discovery of nuclear winter obviously entails changes in our strategic policy.

I thank you very much.

Mr. **Udall**. Thank you, Secretary Perle, you're effective and articulate, and I'm really pleased you took the time at this important juncture to come and be with us. I think this nuclear winter issue is going to be increasingly debated in the Congress, and I hope we can have a high level of debate.

I personally hadn't intended—I don't think any of us intended—to turn this into a debate between you and Dr. Sagan, but you are two articulate people, and I'm not sure we can settle all the differences between you here today, but I do appreciate your——

Mr. **Perle**. Mr. Chairman, let me just say that the prepared statement which I dispensed with after listening to Dr. Sagan did not anticipate a debate.

Mr. **Udall**. I understand.

Mr. Scheuer.

Mr. **Scheuer**. Thank you, Mr. Chairman.

Secretary Perle, I want to express my appreciation for your being here today. We find your testimony absorbing and challenging and fascinating. Of course, I think—incidentally, I would ask unanimous consent that Secretary Perle's prepared testimony be printed in full in the record.

Mr. **Udall**. Do you desire to have this included, Secretary Perle?

Mr. **Perle**. I think we could get it over to the committee this afternoon.

Mr. **Scheuer**. Fine.

Mr. **Perle**. There was a point or two in it I didn't much like anyway.

Mr. **Scheuer**. Fine.

Mr. **Udall**. Thank you.

[The prepared statement of Mr. Perle follows:]

STATEMENT OF
RICHARD N. PERLE
ASSISTANT TO THE SECRETARY OF DEFENSE
FOR ATOMIC ENERGY
MARCH 14, 1985

MR. CHAIRMAN,

I WELCOME THIS OPPORTUNITY TO APPEAR BEFORE YOU. RECENT SCIENTIFIC WORK SUGGESTING THAT MAJOR NUCLEAR EXCHANGES COULD PRODUCE DRAMATIC CLIMATOLOGICAL CHANGE IS EXTREMELY IMPORTANT. WE TAKE IT VERY SERIOUSLY. INDEED WE FUNDED MUCH OF THE RESEARCH WHICH HAS ALREADY OCCURRED, AND WE ARE NOW UNDERTAKING AN EXPANDED RESEARCH PROGRAM TO INCREASE OUR UNDERSTANDING OF THE PHENOMENON INVOLVED. BUT IT IS IMPORTANT, ESPECIALLY FOR THIS MORNING'S HEARING, THAT WE BE VERY CLEAR ABOUT WHAT WE KNOW ABOUT THE SCIENCE IN THIS AREA, AND WHAT WE DO NOT. MOST IMPORTANTLY WE NEED TO UNDERSTAND WHAT BOTH OUR KNOWLEDGE OF NUCLEAR WINTER, AND OUR LACK THEREOF, IMPLIES FOR OUR NUCLEAR POLICY.

WE UNDERSTAND TODAY THAT IF A SUFFICIENT AMOUNT OF SMOKE, DUST, AND OTHER OBSCURANT MATERIAL IS PLACED BETWEEN THE EARTH AND THE SUN, SEVERE ENVIRONMENTAL EFFECTS WILL BE THE RESULT. SCIENTIFIC STUDIES ON THIS SUBJECT HAVE ESTABLISHED, HOWEVER, THAT MAJOR UNCERTAINTIES EXIST ON A NUMBER OF CRUCIAL POINTS. WE RECOGNIZE THIS FACT, AND BELIEVE OTHERS IN THE SCIENTIFIC COMMUNITY UNDERSTAND THAT A SIGNIFICANT RANGE OF UNCERTAINTY EXISTS AS TO PRECISELY THE NUMBER OF WEAPONS AND CIRCUMSTANCES THAT COULD CAUSE A CLIMATIC CHANGE. FURTHERMORE THERE IS LITTLE AGREEMENT WITHIN THE SCIENTIFIC COMMUNITY ON THE TECHNICAL UNDERPINNINGS OF NUCLEAR-INDUCED GLOBAL CLIMATOLOGICAL CHANGE BECAUSE OF THE LARGE

NUMBER OF ASSUMPTIONS ONE MUST MAKE TO DEVELOP AN ESTIMATE OF THE RISK OF TRIGGERING THIS PHENOMENON. FOR EXAMPLE, THERE ARE DIFFERENCES MEASURED IN FACTORS OF TEN AS TO THE NUMBER AND NATURE OF THE FIRES THAT WOULD START, THE NUMBERS OF WEAPONS OR TYPES OF ATTACK THAT WOULD CREATE THEM, AND THE AMOUNT OF MATERIAL BURNED AND SMOKE SUCH FIRES WOULD GENERATE. SOME ANALYSES HAVE SIMPLY ASSUMED THAT FIRES WOULD BURN VIRTUALLY EVERY MOLECULE OF MATERIAL, CONVERT IT TO POLLUTANTS AND INJECT IT INTO THE UPPER ATMOSPHERE WELL ABOVE THE POINT WHERE PRECIPITATION COULD SERVE TO WASH IT OUT. OTHERS BELIEVE THAT SOME FIRES MAY NOT START BECAUSE OF LOCAL RAIN OR SNOW COVERING OR THAT SUBSEQUENT DETONATIONS COULD EXTINGUISH EXISTING FIRES. LOCAL WEATHER CONDITIONS COULD ALSO ACT TO REMOVE DUST WHICH HAD ENTERED THE ATMOSPHERE AS A CONSEQUENCE OF NUCLEAR EXPLOSIONS -- THE SO CALLED "WASH-OUT EFFECT." THESE POINTS SERVE TO ILLUSTRATE THE WIDE RANGE OF QUESTIONS FOR WHICH NO ANSWERS EXIST TODAY, AND WHICH WE ARE SEEKING TO RESOLVE.

ALL WE CAN REALLY SAY WITH CONFIDENCE TODAY, THEN, IS THAT WE BELIEVE SOME PORTION OF ALL THIS SMOKE AND DUST WOULD REACH THE UPPER ATMOSPHERE, WHERE, OVER TIME, CIRCULATION WOULD BEGIN TO SPREAD IT OVER WIDER AND WIDER AREAS. THESE POLUTANTS WOULD NOT INSTANTANEOUSLY BLANKET THE EARTH WITH AN OPTICALLY DENSE MASS (AS A FEW STUDIES HAVE ASSUMMED) BUT RATHER, THIS SUSPENDED PARTICULATE MATTER COULD ACT MUCH LIKE A CLOUD: ABSORBING AND

SCATTERING SUNLIGHT AND REDUCING THE AMOUNT OF SOLAR ENERGY THAT COULD POTENTIALLY REACH THE EARTH'S SURFACE. HOW MUCH AND HOW FAST THE SURFACE OF THE EARTH MIGHT COOL, IF AT ALL, WOULD DEPEND ON MANY OF THE AS YET UNDETERMINED DETAILS OF THIS ENTIRE PROCESS. THUS, WE CAN ONLY CONCLUDE THAT THERE IS NO SCIENTIFIC EVIDENCE TO SUGGEST THAT AS FEW AS 100 WEAPONS OR AS MANY AS SEVERAL THOUSANDS OF WEAPONS WOULD HAVE A LONG-TERM EFFECT ON GLOBAL WEATHER.

WHETHER OR NOT THIS HYPOTHESIS REPRESENTS A REAL OUTCOME FOR THE WIDE-RANGE OF NUCLEAR WAR SCENARIOS AND THEIR ASSOCIATED VARIABLES, SIMPLY CANNOT NOW BE DETERMINED. NEVERTHELESS, AS I SAID A MOMENT AGO, WE TAKE THIS SUBJECT VERY SERIOUSLY. WE HAVE INITIATED A MAJOR, RESPONSIBLE, RESEARCH PROGRAM DESIGNED TO REDUCE THE UNCERTAINTY. I CANNOT SAY THE SAME FOR OUR SOVIET COUNTERPARTS.

FOCUSING SOLELY ON THE ACTUAL NUCLEAR WINTER PHENOMENON, AND ON THE SCIENTIFIC UNCERTAINTIES WHICH ATTEND IT, HOWEVER, HAS A SEDUCTIVE AND DANGEROUS EFFECT. DISCUSSING WHAT LEVEL OF NUCLEAR EXCHANGE MIGHT CREATE WHAT EFFECT ON THE CLIMATE TENDS TO DIVERT OUR ATTENTION FROM THE MOST FUNDAMENTAL QUESTION FACING US. WE HAVE NO UNCERTAINTIES ABOUT THE HORRIFIC SHORT-TERM CONSEQUENCES OF NUCLEAR WAR. SUCH AN EVENT WOULD REPRESENT AN UNPARALLELED CATASTROPHE WHICH WOULD HAVE NO WINNERS. THIS

IS WHY OUR POLICY SEEKS TO PREVENT SUCH AN OCCURRENCE. EVEN THE POSSIBILITY THAT THESE SHORT-TERM EFFECTS OF BLAST AND RADIATION WOULD BE AUGMENTED BY LONGER-TERM ATMOSPHERIC AND CLIMATIC CHANGES REINFORCES THE IMPORTANCE OF DETERRING NUCLEAR WAR.

AS SECRETARY WEINBERGER'S RECENT REPORT ON THIS SUBJECT TO THE CONGRESS MAKES CLEAR, WE ARE TAKING STEPS THROUGH OUR MODERNIZATION EFFORTS TO ENSURE THAT WE CONTINUE TO HAVE A CLEAR AND CREDIBLE CAPABILITY TO DETER SOVIET AGGRESSION WHICH COULD BEGIN WITH, OR RESULT IN, NUCLEAR WAR.

OUR ARMS REDUCTION POLICY REPRESENTS A SECOND, CRUCIALLY IMPORTANT, INITIATIVE WHICH BEARS ON THE SUBJECT OF NUCLEAR WINTER. THIS ADMINISTRATION BELIEVES THAT THE LEVEL OF NUCLEAR WEAPONS THAT EXISTS TODAY ON BOTH SIDES IS UNACCEPTABLY HIGH. AS A RESULT, WHERE IT HAS BEEN POSSIBLE TO REDUCE NUCLEAR WEAPONS UNILATERALLY -- PARTICULARLY WHERE BOTH CONVENTIONAL AND NUCLEAR MODERNIZATION PROGRAMS ALLOW REPLACEMENT OF EXISTING SYSTEMS ON LESS THAN A ONE-FOR-ONE BASIS, WE HAVE UNDERTAKEN TO DO SO. THESE INITIATIVES HAVE REDUCED THE NUMBER OF U.S. NUCLEAR WEAPONS BY ONE-THIRD SINCE 1967 AND HAVE CUT THE YIELD OR MEGATONNAGE BY A FACTOR OF FOUR, SINCE THE EARLY 1960s. WE WILL CONTINUE THIS PROCESS WHERE WE CAN. IN FACT, WHEN THE NATO DEFENSE MINISTERS MET IN CANADA LATE IN 1983, THEY DECIDED TO TO REMOVE YET ANOTHER 1,400 WEAPONS FROM NATO'S SOIL. BUT I MUST TELL YOU THAT MAJOR REDUCTIONS IN NUCLEAR WEAPONS CAN ONLY BE ACHIEVED THROUGH

NEGOTIATING MUTUAL AND VERIFIABLE REDUCTION AGREEMENTS. WE HAVE TAKEN SUCH PROPOSALS TO GENEVA TO ENGAGE IN NEW TALKS WITH THE SOVIETS. WE HOPE VERY MUCH THAT THEY WILL RESPOND SERIOUSLY, AND THAT TOGETHER WE CAN AGREE TO MUTUAL VERIFIABLE REDUCTIONS.

OUR ARMS REDUCTION PROPOSALS RELATE TO NUCLEAR-INDUCED CLIMATOLOGICAL CHANGES IN TWO WAYS. FIRST, AGREEMENT RESULTING FROM SUCH PROPOSALS CAN STRENGTHEN DETERRENCE -- THE MOST DIRECT WAY AVAILABLE TO US TODAY FOR DEALING WITH THE POSSIBILITY OF SEVERE CLIMATIC EFFECTS. SECONDLY, THEY CAN TO SOME EXTENT MITIGATE THE EFFECTS IF DETERRENCE WERE TO FAIL.

BUT THERE ARE NOW THOSE WHO SUGGEST THAT, IN LIGHT OF NUCLEAR WINTER, THE GOAL OF ARMS REDUCTIONS MUST BE MODIFIED TO FOCUS ON REDUCING THE NUMBER OF NUCLEAR WEAPONS BELOW THE LEVEL WHICH THEY CALCULATE MIGHT TRIGGER SIGNIFICANT CLIMATOLOGICAL CHANGE -- CALCULATIONS THAT, AS I NOTED EARLIER, WERE BASED ON ASSUMPTIONS AND UNCERTAINTIES, WHICH WHEN MULTIPLIED TOGETHER, RESULT PERHAPS IN ERRORS MEASURED BY FACTORS OF TENS RATHER THAN UNITS. BUT THESE NEWLY-MINTED ARMS CONTROL "EXPERTS" ARE ENGAGING IN IRRESPONSIBLE POLICY ANALYSIS, BECAUSE THEY IGNORE THE FACT THAT A NUCLEAR WAR CONDUCTED WITH THE ARSENALS REMAINING AFTER THEIR PROPOSED REDUCTIONS WOULD STILL CREATE UNACCEPTABLE LEVELS OF DEATH AND DESTRUCTION. LOOKING TO ARMS CONTROL FOR FRACTIONAL REDUCTION IN FATALITIES BY ELIMINATING LONGER-TERM EFFECTS WHILE

PRESERVING SHORTER-TERM ONES IS AS NAIVE AND IRRESPONSIBLE AS BEING SATISFIED WITH "ARMS CONTROL" THAT PERMITS INCREASES RATHER THAN DECREASES IN THE LEVELS OF ARMS. WE HAVE HAD THIS KIND OF ARMS CONTROL IN THE PAST AND IT HAS HELPED TO BRING US TO THE PERILOUS SITUATION IN WHICH WE NOW FIND OURSELVES.

THUS IT IS ESSENTIAL TO KEEP THE LIMITATIONS AS WELL AS THE BENEFITS OF POTENTIAL ARMS REDUCTIONS CLEARLY IN VIEW WHEN ASSESSING WHAT ONE SEEKS TO ACCOMPLISH THROUGH THIS PROCESS. OUR OBJECTIVES ARE TO STRENGTHEN DETERRENCE IN THE NEAR-TERM AND TO BEGIN A PROCESS THAT IN THE LONG-TERM CAN LEAD TO A WORLD IN WHICH PEOPLE DO NOT HAVE TO CALCULATE FATALITIES.

THE TYPE OF ARMS CONTROL THIS ADIMINSTRATION SEEKS WILL NOT BE ACHIEVED WITHOUT DIFICULTY, BECAUSE WE HAVE KNOWINGLY AND WILLINGLY SET A STANDARD FOR ARMS CONTROL THAT IS FAR MORE DEMANDING AND RIGOROUS THAN THE U.S. HAS EVER SET FORTH BEFORE IN ANY ARMS PROPOSAL WITH THE SOVIETS. AS A RESULT, IT IS GOING TO MAKE IT HARDER TO REACH AN AGREEMENT -- BUT IT IS WORTH THE EFFORT.

THERE IS A THIRD INITIATIVE, STRATEGIC DEFENSE, WHICH COMPLEMENTS ARMS REDUCTION AND WHICH COULD ACT, IF EVENTUALLY DEVELOPED AND DEPLOYED, TO REDUCE THE RISKS OF WAR. SHOULD DETERRENCE FAIL, DEFENSES COULD MITIGATE SUBSTANTIALLY BOTH THE

SHORT- AND LONG-TERM EFFECTS BY REDUCING THE NUMBER OF BALLISTIC MISSILE WARHEADS THAT WOULD REACH THEIR TARGETS. THIS COULD FACILITATE THE TRANSITION TO A MORE STABLE WORLD, WITH GREATLY REDUCED LEVELS OF NUCLEAR ARMS AND AN ENHANCED ABILITY TO DETER WAR BASED UPON AN INCREASING CONTRIBUTION OF NON-NUCLEAR DEFENSES. AND THIS PERIOD OF TRANSITION COULD LEAD TO THE EVENTUAL ELIMINATION OF ALL NUCLEAR ARMS, BOTH OFFENSIVE AND DEFENSIVE.

THE DEPARTMENT OF DEFENSE HAS UNDERSTOOD FOR A VERY LONG TIME THE IMMENSE TRAGEDY A NUCLEAR WAR WOULD BRING TO THE WORLD -- WITH OR WITHOUT A NUCLEAR WINTER. THUS, OUR CURRENT POLICIES OFFER THE PRUDENT APPROACH IN DEALING WITH THE QUESTION OF NUCLEAR WAR, INCLUDING ITS POTENTIAL EFFECT ON THE CLIMATE. WHAT I FIND DIFFICULT TO UNDERSTAND, THEREFORE, IS WHY MANY INDIVIDUALS NOW ASSUME THAT THE POSSIBILITY OF NUCLEAR WINTER REQUIRES, DEMANDS, THAT WE CHANGE OUR POLICY. THEY DO SO, IN MANY CASES, WITHOUT EVEN BOTHERING TO TAKE THE TIME TO DETERMINE WHAT OUR POLICY IS, AND HOW IT WORKS. FOR EXAMPLE, SOME ANALYSES OF THE "NUCLEAR WINTER" EFFECT HAVE ASSUMED TARGETING OF CITIES. IF THIS WERE REGARDED AS AN INEVITABLE RESULT OF NUCLEAR ATTACK, OR AS U.S. POLICY, IT WOULD COMPLETELY DISTORT ANALYSIS OF CLIMATIC EFFECTS. MORE IMPORTANTLY, IT WOULD PERPETUATE A BASIC MISPERCEPTION OF THE NATURE OF DETERRENCE. ATTACKS DESIGNED TO STRIKE POPULATIONS WOULD, BY VIRTUE OF DELIBERATELY TARGETING

HEAVILY BUILT UP URBAN CENTERS, NECESSARILY HAVE A HIGH PROBABILITY OF STARTING MAJOR FIRES. WE BELIEVE THAT THREATING CIVILIAN POPULATIONS IS NEITHER A PRUDENT NOR A MORAL MEANS OF ACHIEVING DETERRENCE, NOR IN LIGHT OF SOVIET VIEWS, IS IT EFFECTIVE. OUR STRATEGY INTENTIONALLY DOES NOT TARGET POPULATIONS AND, IN FACT, HAS PROVISIONS FOR REDUCING CIVILIAN CASUALTIES. AS PART OF OUR MODERNIZATION PROGRAM, WE ARE RETIRING OLDER DETERRENT SYSTEMS WHICH MIGHT CREATE A GREATER RISK OF CLIMATIC EFFECT THAN THEIR REPLACEMENTS.

AS A FINAL POINT, MR. CHAIRMAN, I WOULD NOTE THAT THE SOVIETS HAVE CLAIMED THAT THEY "INDEPENDENTLY" CONFIRMED THE PROBABILITY OF A "NUCLEAR WINTER" AS A CONSEQUENCE OF A NUCLEAR WAR. EXAMINATION OF SOVIET STUDIES ON THIS ISSUE, HOWEVER, SHOWS THAT THERE IS NO BASIS FOR THIS CLAIM. SOVIET SCIENTISTS HAVE ESSENTIALLY BORROWED THE WORK OF OTHERS, INCLUDING OBSOLETE GLOBAL CIRCULATION COMPUTER MODELS FROM THE UNITED STATES, AND PARROTED IT BACK IN THE GUISE OF INDEPENDENT WORK. THE FACT IS THE SOVIETS HAVE CONTRIBUTED VERY LITTLE TO THE WORLD'S UNDERSTANDING OF THE ISSUES INVOLVED IN THIS THEORY. AND I MUST TELL YOU FRANKLY THAT IT IS OFTEN DIFFICULT TO DISTINGUISH BETWEEN SOVIET SCIENTISTS AND PROPAGANDISTS. THE FLOW OF USEFUL INFORMATION HAS BEEN ONE-WAY, WITH WESTERN SCIENTISTS DOING ALL THE WORK. THE SOVIETS ARE AWARE OF THE UNCERTAINTY ASSOCIATED WITH THIS THEORY AND THEY ARE NOT EXPENDING ANY FUNDS TO REDUCE IT

WHEN THEY CAN HAVE OUR WORK WITHOUT CHARGE.

FOR THE MOST PART, THE SOVIET LEADERSHIP HAS SHOWN NO INDICATION OF OFFICIAL RECOGNITION OF THIS THEORY, NOR HAVE WE OBSERVED ANY CHANGES IN THE DIRECTION, MAGNITUDE OR PACE OF SOVIET STRATEGIC WEAPONS PROGRAMS SINCE THE THEORY WAS FIRST PROMULGATED. SO WHILE THE SOVIETS WOULD LIKE THE WORLD, AND IN PARTICULAR OUR PUBLICS, TO BELIEVE THAT THEY ARE TREATING THIS ISSUE SERIOUSLY, IN FACT, THEY APPEAR ONLY TO BE EXPLOITING THE THEORY FOR PROPAGANDA VALUE -- AND AS A CONVENIENT COVER TO GAIN ACCESS TO WESTERN SCIENTISTS AND OUR TECHNOLOGY. YOU SHOULD KNOW, FOR EXAMPLE, THAT THE SOVIETS HAVE USED THE NUCLEAR WINTER ISSUE TO REQUEST ACCESS TO U.S. SUPER-COMPUTERS, SOFTWARE MODELS AND MODELING TECHNIQUES. HERE LIES AN ULTIMATE IRONY -- THAT IN THE GUISE OF EXPRESSING CONCERN ABOUT THE CLIMATIC DANGER OF NUCLEAR WAR THE SOVIETS ARE SEEKING TO STEAL WESTERN TECHNOLOGY TO IMPROVE THEIR NUCLEAR ARSENAL.

MR. GHAIRMAN, I BELIEVE THESE OPENING REMARKS HAVE DEMONSTRATED THAT THIS IS A VERY COMPLEX AND IMPORTANT ISSUE. IT INVOLVES A WIDE RANGE OF CRUCIAL NATIONAL SECURITY ISSUES. IT DEMANDS OUR ATTENTION, BOTH IN ITS NARROW, CLIMATOLOGICAL ISSUES AS WELL AS IN THE BROADER CONCERNS OF WAR AND PEACE WHICH IT TOUCHES AND AFFECTS. I URGE THAT THE PUBLIC DEBATE TREAT IT ATMOSPHERE WHICH ALL TOO OFTEN SURROUNDS IT. I WELCOME YOUR INVESTIGATIONS AS A STEP IN THE RIGHT DIRECTION.

Mr. Scheuer. I think there's total unanimity here that, above all, the one point that is first among equals of all the points that we are trying to make is the absolute necessity of avoiding any kind of nuclear confrontation, any kind of nuclear exchange, any kind of even a first nuclear strike.

But it does seem to me a legitimate matter for us to say, in setting our nuclear strategy, have you factored into that strategy what we now seemed to have learned, albeit with a certain amount of fuzziness in terms of the actual quantification, what we've learned about the possibility of this whole new phenomenon developing after the initial nuclear strike, the phenomenon we're discussing known as nuclear winter. It seems to me that, in this very sophisticated process of developing a nuclear strategy in which you consider all kinds of elements, that that is certainly one element that ought to be considered.

For example, in the sixties, we had a strategy then—I guess developed by General Curtis LeMay—of bombing them back to the Stone Age. It seems to me that that Armageddon approach would be fraught with peril for us today, and that that would not be a preferred nuclear strategy. As a matter of fact, from the information that we have—and believe me, I do not pose as an expert in this area whatsoever—you have factored in restraints. You do have in the SIOP one restraint that is called Restraint on Collateral Damage, where it's the policy, as I understand it, to use the smallest possible weapon to take out a given target. That is the kind of thing we're thinking of.

Have you developed a comparable restraint that would be directed at avoiding the phenomenon of nuclear winter——

Mr. Perle. Yes.

Mr. Scheuer [continuing]. That would produce some kind of urban burn index, so that you would know how many cities you could target at any one time—given the distances between them, the climatic conditions, the time of year, the prevailing winds, and so on, and so forth—so that whatever your strategy was and whatever the exigencies of the moment were, you would avoid the secondary phenomenon—in the horrifying event of a nuclear strike, you would at least avoid the nuclear winter effect? Has that been factored into your thinking? Is there some kind of a committee that is thinking about this? Is there further research being done? Who are the members of the committee? What Members of Congress are involved in thinking this through? I think these are the kinds of questions we are interested in hearing about.

Mr. Perle. I think those are fair questions and, if I may say so, they're constructive ones.

Mr. Scheuer, for reasons preceding the discovery of nuclear winter, we have—many of us anyway—have long believed that it is in our interest, including in our moral interest, to reduce to the maximum possible extent the unintended or collateral damage that would occur as a consequence of a nuclear exchange. And much has been done in this direction, including the reorganization of the President's strategic targeting options, so that he can withhold weapons from targets where significant collateral damage would be an inevitable consequence. That work, that study, and that investigation continues through a variety of mechanisms, both in the Department of Defense and in the Strategic Air Command, and elsewhere, and I can assure you that we will continue with vigor renewed by the understanding of nuclear winter to pursue that general direction. We have tried for some years now.

The irony is, if I may say so, that when some targeting doctrinal changes were introduced a few years ago in order to move in this direction, the cry that we heard from many of those who are now most insistent on the need to respond to nuclear winter was that we were converting to a war-fighting strategy, moving away from mutual assured destruction, and thereby further endangering the planet. So I think we were ahead of our critics in recognizing that collateral damage, if it can be avoided, ought to be avoided, and we are working to do that.

Now for the future, there are even some promising developments with respect to improvements in conventional forces that, in a number of situations, might permit us to replace nuclear weapons with conventional weapons. And this is something that we ardently desire to do, something that we're pushing rather hard both within the Department of Defense and with our allies.

So the answer to the question is yes, we are mindful of the need to take these phenomena into account. But let me say that, given the very great range of uncertainty as to the number of weapons and under what circumstances it would take to cause the nuclear winter phenomenon, it is very difficult to be precise about how quantitatively our targeting options ought to be adjusted. We simply don't have the information on which to base that. And I wish Dr. Sagan would go to work on helping us solve that problem instead of playing political scientist for us.

Mr. SCHEUER. Secretary Perle, there are two studies that apparently are significant and important, the CADRE study that has been referred to and the Palomar study that hasn't been referred to. At best, we would hope they could be released to the public; at the very minimum, we would hope they could be made available to Members of Congress who have a top secret rating. Can you give us some assurance that these will be made available at least to the Congress and, hopefully, made public?

Mr. PERLE. I'm not familiar—I have not read either study. Frankly, I'd like to read them first. We do have some limited pride of authorship, even though we're a bureaucracy, and if the CADRE study is superficial and inadequate, as I am informed it is, I think we'd be embarrassed to release it.

Mr. SCHEUER. The Palomar study, too.

Mr. PERLE. The Palomar study, I'm not familiar with at all.

But let me say we are not going to suppress the view of some officer who may have written some opinion that differs from the opinion of the administration. There are plenty of other people who can give expression to all of those views, and we enjoy the debate. And the suggestion that we are somehow suppressing dissident ideas about the implications of nuclear winter is just fundamentally wrong and unfair.

Mr. SCHEUER. Judging from your performance this morning, you're well equipped, well qualified to cope with any debate that's likely to come in the future.

Thank you, Mr. Chairman.

Mr. **Udall**. Mrs. Schneider.

Mrs. **Schneider**. Secretary Perle, are you of the opinion that the information that has been included in the DOD report ought to be expanded to incorporate some biological, agricultural, and societal impact studies?

Mr. **Perle**. Let me say I'm not sure—I think it is vital to the decisions that the Government has to make to explore every last physical phenomenon associated with nuclear war. We are well persuaded that nuclear war would be terribly destructive. And whether it—it is a bottomless pit for research, given the inability to conduct experimental research, to speculate on all of the horrifying consequences of such a war.

Mrs. **Schneider**. One of the questions——

Mr. **Perle**. So I have no objection in principle to it, but it's not at all clear to me that this would be a useful investment of limited research resources.

Mrs. **Schneider**. One of the questions that this Science Committee so often is required to ask is that, in the pursuit of answers to scientific questions or looking for scientific answers, we have to recognize when is enough research enough research, and obviously our discussions on acid rain have pretty much concluded we've been doing plenty of research. Yet the administration is asking for more money for additional research. And oftentimes it is perceived that this might be a way of saying, well, we just want to keep on researching it because we don't want to take any mitigating measures.

I think there is concern among many Members of Congress—and I certainly appreciate your comment—we can spend lots and lots of money researching this thing, but at what point and what information will be necessary to change the attitude and the policies of the administration and those who are sitting in this body?

Mr. **Perle**. But you see, there again is the presumption that if we only understood the phenomenon, if we only realized the circumstances under which a nuclear winter would occur, we would change our policies, which implies that the policies are an inappropriate response to the prospects of a horrible nuclear war, and I don't believe they are. You've been begging the question, all of you.

I heard you say earlier that we have a view of warfare of the more weapons the better. I don't know whose view that is. That is not the view of the Department of Defense. It's certainly not my view.

Mrs. **Schneider**. Then why in the constant debates before the Armed Services Committee and the debates on the floor do we—are we shown charts by members of the leadership here in this body saying this is how many submarines the Soviets have and this is how many submarines the United States should have in order to keep up with the Jones? I think that's the kind of mentality that is working among the decisionmakers now, and I think that—I agree with you that that is a frightful way to be making, and a very uneconomical way to be making decisions as to what our deterrent posture ought to be.

Mr. **Perle**. But it's not how we do it.

Mrs. **Schneider**. It is how we do it here.

Mr. **Perle**. It may be that there are charts showing the relative forces on each side. But when we make a decision to develop a weapon or to procure a weapon, it is not because the Soviets have the same weapon or because they have them in larger numbers. The Soviets have vastly more air defenses then the United States—13,000 launchers for surface-to-air missiles. We don't have a system like that. We haven't even begun one. Nor do we have any intention of doing so.

So I think it's wrong to suggest that we are keeping up with the Jones. I really believe that trivializes the very difficult problem we have in planning our strategic forces. And most of what we are now doing—most of what we are now doing represents the replacement of obsolete systems that were deployed 20 and 25 years ago that are nearing the end of their useful operational life.

Mrs. **Schneider**. Well let me get back to my original line of questioning. Your budget for the Department of Defense this past year has been $1½ million and it is slated for an increase of $2½ million in '86. Whether that occurs or not remains to be seen. There are many of us who are looking at straight across-the-board freezes, including this area.

I'm curious to know whether or not, seeing you question the need for continued research, is that kind of increase warranted?

Mr. **Perle**. Yes; I think there is a lot that we don't know. And I'm sure that Dr. Sagan would acknowledge that there is a lot that we don't know about the phenomena that he has in general terms described. We need to know more: What are the washout consequences of moisture in the atmosphere? How do different materials with different properties burn and under what circumstances do they burn? How does the weather at the time of the war affect the calculation, and so forth?

At the end of the day, there's still going to be very sizable uncertainty. I don't think there is any question about that. But we ought to do what we can to narrow the uncertainties that now exist.

All that has been determined thus far, in my judgment, is that, at some level of nuclear exchange, there may well be climatic effects, and we take that very seriously. But I want to assure you we took very seriously the prospect of hundreds of millions of deaths even before we knew about nuclear winter.

Mrs. **Schneider**. We are collaborating here, questioning how the attitude of that seriousness is reflected in the report.

Mr. **Perle**. I think the report is a good report. It is a report intended to be read for one thing. I mean, we could have sent you 800 or 900 pages, which is the typical bureaucratic way to do it, and nobody would have read it, probably not even the staffs. It is a readable report. I think it is a fair and accurate report with respect to the implications of the nuclear winter phenomenon. I don't think the length of the report is the standard by which we should judge whether the issues have been identified.

I realize there is disappointment that we did not at the conclusion of this report say we are going to abandon our historic attitude toward the construction of our strategic forces and the nature of our deterrent and our approach to arms control. I'm sorry about that, that we couldn't satisfy you on that count. But that's because we believe that what we are doing with respect to our strategic force posture and arms control is basically sound, and it is made no less sound by the recognition that there are phenomena beyond those we already understood that would make a nuclear war even more horrible than we had already anticipated.

Mrs. SCHNEIDER. Well said. Thank you very much, Mr. Perle.

Thank you, Mr. Chairman.

Mr. SCHEUER [presiding]. Mr. Wirth.

Mr. WIRTH. Thank you, Mr. Chairman.

Secretary Perle, as you know, this amendment grew out of a seminar which Congressman Gingrich and I sponsored for Mr. Teller and Mr. Sagan to come and talk to a large number of Members of Congress, and I will speak to Congressman Gingrich. But let me in advance invite you and Dr. Sagan to come back and maybe we could get the two of you together with that, because I think the implications of this discussion we've had today are very significant and ones that many members should have the benefit of.

I might also suggest that when you talk about the CADRE study, it is my understanding that the General Accounting Office had done a preliminary look at the CADRE study and had agreed that it was not a particularly distinguished piece of work. I would hope we might get your analysis of that back, as has been requested before, as well as an analysis and understanding as to what the Palomar study was and why that was not included in the report that came back to the Congress on the first of March.

[See appendix for Perle letter.]

Also, you might have your staff send to us, if you might, the actual facts on the dollars extended in all of this. There seems to be some debate about that which you raised earlier saying that, in fact, a certain amount of money was spent. Science Magazine had a different outline of that. Science had suggested, as best the story can be pieced together, George Keyworth, the President's Science Adviser, first sought to extract roughly $5 million in new funds entirely from DOD, and it goes on to say that that money was not forthcoming. I think we'd like to just have a picture of who was doing what. [See appendix for Science article and response for record.]

Mr. PERLE. It's simply a question of who pays the bills. You know, everybody thinks you can come to the DOD and tap into our budget.

The fiscal year 1986 proposal is $5.5 million total on an interagency basis; $2½ million of that will come from the Defense Department, $5 million of it from the Defense Department and the Department of Energy together. So we are, in fact, funding the burden of this.

I must say in this connection that I think this money will be well spent by competent scientific personnel——

Mr. WIRTH. I'm not debating that.

Mr. PERLE [continuing]. Able to make the measurements that we're talking about. I resent—I'm sorry I neglected to mention this earlier—the implication that the only independent scientists are university scientists. You know, there are a lot of things that affect one's scientific judgment other than who pays your salary.

Mr. WIRTH. Dr. Perle, I appreciate that. I appreciate your perspective on that, some of which I agree with, some of which I don't.

I have a limited amount of time and I do want to get on the record, you know, who's paying for what and how much is being committed.

Let me go to the thrust of my questioning which relates not to the uncertainty of the science—I think you and I should leave that to scientists—but to the policy implications of nuclear winter. What concerned me in the report that we received from the Department of Defense was, on the one hand, agreeing that nuclear winter as a phenomena was a valid scientific concept—we're going to hear more specifically about that in later witnesses this morning.

What concerned me, however, was the unwillingness or apparently nonrecognition that there might well be other implications that came out of the concept of nuclear winter. And let me give you three that, you know, I think I understand: One, the notion of survivability. That has been a concept which has been advocated by members of this administration and previous administrations that, in fact, there was such a thing as a survivable nuclear war. If the concept of nuclear winter is valid, what are the implications of that for the concept of survivability?

Second, targeting, which has been referred to. I think the situation is more ambiguous than one that anybody has suggested today. Maybe one can come out and say that there are no implications whatsoever. On the other hand, you can't say, I think, as the report from the Department of Defense suggests, that there is no targeting of urban areas. I mean, you know and I know that that is not the case.

The third concept, it seems to me, that ought to be examined in the light of the nuclear winter issue is the notion of a first strike. We hear an enormous amount of rhetoric and discussion over the last years, particularly in the debate on the MX missile about what is first strike, what is not first strike. If nuclear winter is a valid scientific concept, does that or does it not put—make bankrupt the notion of first strike? The first strike, in fact, would be suicide; consequently we should not base a number of our targeting and other initiatives on the concept of first strike.

There are a variety of implications of nuclear winter that break into the discussion of arms control, suggest different implications which I think it is our responsibility and yours to wrap our heads around as best as possible.

Mr. **Perle**. Let me just say that I think it is—it is very difficult to go from the conclusion that nuclear winter is a valid concept to the conclusion that how one conducts or how one responds to a first strike, or how one targets or does not target, or the issue of survivability—how we will reflect on that as a consequence of the concept. Because the concept, without diminishing the uncertainty, the quantitative uncertainty, isn't a very helpful guide. It can point you in the direction. It points us in the direction, reinforces the direction, of withholding weapons from urban targets. It points us in the direction of seeking forces that are survivable in the face of a Soviet first strike capability. It pushes us in the direction of recognizing that a nuclear war, whether one survives it or not, would entail tremendous and unacceptable destruction.

Obviously, it is tautological that if a—if by what—when you refer to the nuclear winter concept, if what you mean is that there will be a nuclear winter as a consequence of any nuclear war and that that nuclear winter will extinguish life on earth, then I don't think you have to be a genius to draw the appropriate conclusion about survivability. You're not going to survive.

But when you talk about the circumstances under which a nuclear winter would be triggered and how we and the Soviets—because we have to do this, in a sense, together—might ameliorate the situations, minimize the situations, in which that would occur. That's a far more difficult proposition, and you can't answer that question simply by accepting the concept, because you've got to have some quantitative sense as well.

Mr. **Wirth**. Clearly the thrust of this hearing is not to say, yes, nuclear winter is bad, and nobody disagrees with that, that the consequences would be devastating. What we're trying to suggest is that if nuclear winter as a concept is valid, then that has a number of implications which you are suggesting in your answer now, that has a number of implications for first strike, that has a number of implications for survivability and different kinds of survivability, which I would suggest to you are not addressed in the report.

Now as the author of the amendment requiring the report, it is my responsibility to make sure, as best I can, that the administration fulfills what the Congress asked it to do. And it seems to me that there are a variety of implications in this which are not addressed, which are not—which are conceptual policy in nature, do not deal with the uncertainties of the science, do not deal with a number of the other issues that have been brought up here, but are ones of the—how are we dealing with the various implications of this for such issues again as targeting, first strike, and so on. Those are not sketched out. Some are not even referred to in the report.

Mr. **Perle**. Well, if we've omitted a topic here——

Mr. **Wirth**. Or a variety, yes, that's the——

Mr. **Perle** [continuing]. It's because we wrote our report and you didn't write our report, and you want us to write your report.

Mr. **Wirth**. No. There are a variety——

Mr. **Perle**. And we would be glad to go back——

Mr. **Wirth**. I would just suggest to you there are a variety of things, Secretary Perle, in the amendment itself, language in the amendment—for example, the biological, agricultural consequences which are not addressed in the report. I would just say to you—I don't want to point a finger or be confrontational about this. I just think this is terribly important. A number of Members think this is terribly important, and would hope that it would not be treated, you know, in an offhanded fashion, and I know that you don't intend to do that.

Mr. **Perle**. If we have omitted points, we would be glad to go back and try to address those points. But the main point I wish to make is that the nuclear winter phenomenon parallels in terms of its implications our understanding of the devastating consequences of a nuclear war before nuclear winter was ever discovered and, therefore, much of what we are doing and much of what we have thought about is only reinforced by the discovery of nuclear winter and does not run counter to it. And I could comment, if you wished, on survivability, on targeting and on first strike, but it would all be in the same vein, that because of the consequences of a nuclear war, absent a nuclear winter, we think we are doing the right thing with respect to targeting, and we think our attitude toward diminishing the Soviet incentive to strike first is an essentially sound attitude.

On the biological consequences, again, I think one can carry this too far. And to attempt when we are not even sure—can't be sure—about the circumstances under which there would be climatic changes, to do an elaborate assessment of biological consequences of climatic changes seems to me to miss the point. The point is we are persuaded in the first instance that a nuclear war would be a terrible thing. And we believe we have designed the policies as best we can—and it's an imperfect world—to minimize the likelihood of that war taking place. And understanding better the biological consequences of a period of protracted low temperature would not, in my judgment, alter our efforts to make the world safer and avoid that nuclear war. But if you insisted that we do that kind of research, of course, we'll do it. We'll try to be responsive to the Congress.

But I don't think it has policy implications of the kind that the recognition that there is a phenomenon like nuclear winter has in the first instance. So I think it's a variation on the theme and not fundamental to what you and we are both interested in.

Mr. **Wirth**. Well, I would thank you, Mr. Chairman. I would think it is our responsibility in the Congress to define what we think are the fundamental questions to be asked, and we'll come back to you on that. Thank you, Mr. Secretary

Mr. **Scheuer**. Congressman Lujan.

Mr. **Lujan**. Thank you, Mr. Chairman.

Mr. Secretary, there seems to be the general conception in the committee that the Department of Defense or the Government or Government agencies are doing nothing in that—in that research. Yet I have before me a press release out of Los Alamos just dated March 1 that talks about the nuclear winter being worse in the summer if that—if it were to come about at that time, and the consequences would be different if we have—depending on the amount of rainfall that we have. So it seems to me like there is ongoing research by the Department of Defense on the effects of the nuclear winter.

My problem is this, that we can understand all of those disastrous effects, but that leads us to the conclusion that we ought to avoid the war to begin with so that we are not concerned with the disastrous effects. And from what I see of administration policy, détente—or deterrence, rather—is one way to do it, arms control, the President's stated object of zero weapons on both sides, if that could come about; SDI, the strategic defense initiative, is certainly to immobilize, to make inoperative any weapon that might come along. They certainly are steps that go toward saying we don't want the effects of nuclear winter to ever present themselves. It seems to me like we are in a good direction.

Are there other things besides deterrence, arms control, as are now going on, SDI proposals—are there other things that we can do to eliminate the threat of nuclear war completely? I think that's the way we ought to be going.

Mr. PERLE. I agree with you entirely. One of the things that we are doing, as I indicated earlier, is making reductions in the size of the force and in the megatonnage of the force. And as the accuracy of weapons improves, I think we ought to be able to move further in that direction. And when accuracy becomes quite perfect, we may be able to substitute some nonnuclear for nuclear weapons. Now that is something that we are very keen to do if we can find ways in which to do it.

We have to press on, as you've indicated, with the effort to get the kind of arms control that brings about serious reductions. The kind we've had in the past hasn't done that, and that brings us to the situation we now find ourselves in. So we have knowingly, willingly, and with our eyes open set a standard for arms control that is far more demanding than has ever been set before, and it's going to make it a lot tougher to get an agreement.

Mr. LUJAN. What—what I——

Mr. PERLE. And if we get an agreement, it may help solve this nuclear winter problem, because the agreements we got in the past didn't help it at all.

Mr. LUJAN. Exactly. Exactly.

What I gathered from what Dr. Sagan said is that verification is going to be an impossibility and that we ought to get a warehouse—you know, you bring them in and dismantle them and put them into powerplants. Do you believe that verification is an unreachable goal?

Mr. PERLE. I think it's difficult to answer that question in the abstract, although Dr. Sagan characterized our views saying that arms control was impossible because of verification. I don't hold that view at all.

I think the limits on our ability to verify, together with the Soviet record of violations of existing agreements, suggest that we should be very cautious with respect to some limitations, limitations where a little bit of cheating would go a very long way. But in the main, we have put forward proposals that we think are adequately verifiable.

Mr. LUJAN. This committee is involved, of course, in research and the new technologies and all those sorts of things, although we don't do the Department of Defense funding. It would seem to me like—that funding of verifiable—verification technology should be very high on our agenda because perhaps we won't be able to have a general on site seeing where the targeting is, but at least if we have some sort of new technology or existing technology to be able to verify something.

Mr. PERLE. I think, if I may say so, the idea that emerged in your earlier exchange with Dr. Sagan, that the Soviets—how do we prove to the Soviets, how do we verify that we do not target their cities, seems to me to miss the point. The point is it is not in our interest to target Soviet cities. It wasn't in our interest to target Soviet cities before the discovery of nuclear winter. If one takes nuclear winter seriously, it is even less in our interest today to target Soviet cities, and I think the Soviets are likely to be persuaded by the logic of the situation and not by what we say.

Mr. LUJAN. Thank you, Mr. Chairman.

Mr. SCHEUER. Mr. Huckaby.

Mr. HUCKABY. Thank you, Mr. Chairman.

Secretary Perle, Dr. Sagan had suggested earlier the possibility of a joint high-level scientific study with the Russians to study the effects of a nuclear winter. Would you be in favor of this or opposed?

Mr. PERLE. If Dr. Andre Sakharov represents the Soviet side, I would be 100 percent favor of it. But if the Soviets are going to send over to participate in a study like that scientists who may or may not be associated with the KGB, scientists who are under instructions to come to certain conclusions and not others and to follow the party line, then I don't think one can expect a fruitful scientific exchange. And it seems to me that as long as Dr. Sakharov is kept in the exile he's kept in, we have every right to be deeply suspicious about Soviet science and Soviet scientific exchange.

Mr. HUCKABY. So you're saying you don't think a scenario would exist where you would favor such a study?

Mr. PERLE. I don't think we can expect to get objective and, therefore, useful results under the current circumstances of Soviet manipulation of scientific data for their own purposes.

Mr. HUCKABY. Do you think we should be sharing all the data that we are acquiring and, hopefully, we will acquire in the coming years with the Soviets regarding nuclear winter?

Mr. PERLE. Absolutely. In the absence of an exchange, the Soviets are perfectly competent to evaluate our results. And I believe it's important that the Soviets be as well informed as possible about the nuclear winter phenomenon. It's obviously in our interest that they not, failing to recognize it, behave in a manner that brings it on. So I think we ought to make our research results available to the Soviet Union. You don't need a highly politicized cooperative program in order to do that. The Soviets are, in fact, in my view, better able to evaluate our research when they can do it privately than in the context of an exchange program where they are forced to strike certain poses and attitudes for political reasons.

Mr. HUCKABY. You have spoken earlier of arms reduction and this administration's goal to achieve arms reductions—yet problems with reducing to zero. At what level would you like to see both sides at?

Mr. PERLE. Well, I believe if we could get to zero, we would by no means absolve the defense problem, because nonnuclear forces would continue to exist and we would obviously have a very serious verification problem, because the presence of even a few weapons surreptitiously retained would have an impact comparable to the impact of the first and only possession of nuclear weapons as it emerged in our hands in the closing days of World War II.

For this reason, I believe that we can only hope to achieve a stable complete nuclear disarmament if both sides have deployed defense so that any violation of the terms of that agreement might be met by adequate defensive forces.

Mr. HUCKABY. Wouldn't it make more sense to significantly reduce and then proceed with a star wars type defense for both sides, rather than trying to proceed with a star wars defense while both sides have overwhelming numbers of——

Mr. **Perle**. But that's not what we're doing. We're proceeding with a program of research parallel to a Soviet program of research, and no decision has been made, nor could any intelligent decision now be made, to proceed with the deployment of a defensive system. I don't know what the results of the research are going to be, but our approach to the Soviets in Geneva now is to begin the process of deep reductions. We won't get deep reductions, there's not a prayer we will get deep reductions, if the burden of opinion in this country and in the Congress in particular is that we ought to settle for shallow reductions, because the Soviets would much rather give us shallow reductions. Their proposals are for shallow reductions. If we don't get deep reductions, we're not going to begin to attack the problem of nuclear winter. So I hope you'll bear with us while we try to get an agreement that is going to be difficult to extract from the Soviet side.

Mr. **Huckaby**. Speaking of reductions, the intermediate proposals in Europe, I think you stated that this administration had proposed the total elimination of all intermediate nuclear weapons in Europe. Does this include the French and the British? I thought that was the hangup.

Mr. **Perle**. No. We—I don't believe that was the hangup, although I'm prepared to take the time if you're able to take the time to discuss that issue in detail. We propose the elimination of United States and Soviet intermediate nuclear weapons.

Mr. **Scheuer**. Would you say that a little bit louder?

Mr. **Perle**. We propose the elimination of United States and Soviet intermediate nuclear ballastic missiles and cruise missiles in the INF negotiations. The Soviets claimed that they could not accept this proposal because of the presence of a very modest number of British and French forces that we neither control nor have any responsibility for or authority over. The Soviets knew we were in no position to dispose of the forces of the British and French, and so it was a show stopper, and I believe they knew that. And I believe that any objective assessment of their negotiating behavior in Geneva prior to the walkout makes it very plain that there was only one outcome that they were prepared to agree to, and that was the abandonment by the United States alone, unilaterally, of the NATO plan to deploy cruise missiles and Pershing, too.

Mr. **Huckaby**. Were they willing to reduce them to the same level as what the British and the French have, equivalent?

Mr. **Perle**. They said that they were prepared to reduce to the same level in a manner that would have left the United States with zero and that calculated the British and French forces in a self-serving and unreasonable way.

Mr. **Huckaby**. Thank you, Mr. Chairman.

Mr. **Scheuer**. Congresswoman Meyers.

Mrs. **Meyers**. You mentioned, Mr. Perle, that we had significantly reduced the number of warheads in our arsenal, and would you elaborate on that a little bit? What have we reduced and when did we do it?

Mr. **Perle**. Well, we've done it rather consistently since the peak was reached in 1967. And the reductions have been brought about by the replacement of older weapons with new weapons in which the older weapons were retired and, in many cases, replaced with a smaller number of similar weapons or, in some cases, we simply abandoned that type of weaponry altogether. So the end result has been a reduction of 8,000 in the years since 1967, and the reduction of the megatonnage of that smaller residual force by three-quarters. We have one-quarter today of the megatonnage that we had in the 1960's.

Now there are people who immediately turn around and say, but our weapons now are far more effective. Of course, they are. It's the increased effectiveness that has permitted the reduction to come about, which is one of the reasons why we've never been very enthusiastic about a nuclear freeze. It seems to me a nuclear freeze is inconsistent with the effort to reduce by enabling a smaller and more effective force to provide the same deterrent capability. So it's been a consistent patter of reductions.

In Canada at a meeting of defense ministers in October 1984, it was agreed that a further 1,400 weapons would be withdrawn from Europe. Most of those will be dismantled. In fact, I think they will all be dismantled. So the number continues—continues to go down, but not on the Soviet side.

Mr. **Scheuer**. Congressman Udall.

Mr. **Udall**. Secretary Perle, Mrs. Meyers seems to be talking either about the build-down or a close relative of build-down; is that correct?

Mr. **Perle**. Well, I think the question——

Mr. **Udall**. I think what I am trying to get at, I was surprised at the 8,000 figure, that we actually have 8,000 less warheads or less launchers or less something.

Mr. **Perle**. Less warheads.

Mr. **Udall**. Less warheads. Has that been a process of modernization? Can you briefly tell me how——

Mr. **Perle**. It has been the consequence of the process of modernization.

You talked earlier in your opening statement, Mr. Chairman, about the 1950's, which was an interesting period. In the 1950's, I think it is fair to say, that this country went on a nuclear binge and built every conceivable weapons in a nuclear version. I believe that was a mindless policy. And when it was evaluated toward the end of the 1950's, and in particular in the early 1960's, it was abandoned and we have, since the late 1960's, been reducing the number of nuclear weapons, partly because we recognize that we had overdone it in the 1950's and it was not necessary to possess nuclear weapons on that scale. I think we can go much further than that process.

But if I could take a second of my time, you made one remark about the 1950's that I can't help commenting on, because it's an indication of how often the standard image is wrong, if I may say so.

In the 1950's—and I was stunned to learn this myself—when our nuclear deterrent force consisted entirely—or virtually entirely—of B-47 bombers and a very large number of bombs—that's where some of these reductions have come from—virtually the entire American arsenal of nuclear bombs was located at two military installations, one in Spokane, WA, and one at Limestone, ME. And had the Soviet Union preemptively attacked those two air bases, this enormous deterrent capability of the United States, a capability that probably would have produced a nuclear winter, would have been destroyed on the ground and we would have had no nuclear retaliatory capability.

Mr. UDALL. That's interesting.

Mr. PERLE. And we didn't know it until the end of the—midway through the period, as a result of some pioneering work done at the Rand Corp., we discovered the vulnerability of our strategic force and had to pay attention to that.

Mr. UDALL. Indeed. Could you give us for the record—and maybe it's in the statement you had—some detail on this 8,000 figure, where and what categories it occurred? I think it is an important subject, and I'd like to see it pursued.

Mr. PERLE. Yes, I think we can.

[The information was supplied in classified form.]

Mr. UDALL. Let me close with the—commenting on what you just said on the 1950's. The thing that shocked me and that I was referring to in the statement is that if—we knew nothing about this nuclear winter idea, none of us in the 1950's. We knew that blast was bad and we knew that radiation was bad and that grave damage could be done to the planet in any event. We now find that there's another—probably or possibly another effect that's equally bad to destroy the planet, and maybe worse in some ways. But we could have—we wouldn't have as a country—but we could have theoretically made a first strike thinking that all the damage would have been in the Soviet Union and that the radiation might reach us through global currents and all of the rest. But we could have had the power to commit suicide, in effect, national suicide, without knowing that that power was in our hands. I think that's one of the things that worries the nuclear winter people perhaps the most.

It reminds me of the story of the woman, the wealthy woman, who said to her driver in the limousine, "Drive off the cliff, George, I want to commit suicide." And it seems to me that this is an aspect of it. This is the thing that's new about nuclear winter.

Mr. PERLE. It reminds me of that scene in the W.C. Fields movie where he's about to be hanged, and the hangman says, "Do you have any last comment to make?" And he says, "Yes, this is going to be a great lesson to me."

No; I think your point is well taken. We—we are perfectly capable of doing stupid things because we're not fully aware of the consequences of our acts. It is not our policy to plan for, prepare for or carry out a first nuclear strike against the Soviet Union, and it wasn't in the 1950's either. And we stood by even in the days of our nuclear monopoly and watched the Soviets do a lot of disagreeable things without ever availing ourselves of that unique capability.

Mr. UDALL. Well, that's quite comforting. Why don't we—in that case, why don't we sign the pledge of no first use that's been argued about over the years? The Soviets say, we've signed it, why don't you?

Mr. PERLE. Well, first of all, we take pledges seriously, and when we sign them, we feel bound to act upon them. So we would have to change our policy. Our present policy is that, in the event that we are unable to defend the NATO alliance in Europe with conventional forces, we retain the right to introduce nuclear forces into the conflict. Gratuitously to remove that uncertainty that the Soviets must face would weaken the quality of our deterrent capability in Europe and expose us, in view of the Soviet preponderance in conventional forces, to an increased risk of conflict. And for that reason we don't think it accomplishes very much.

Mr. UDALL. Do our NATO allies still want us not to make such a statement?

Mr. PERLE. Yes; I believe they want us to stand with our current position. And our Gang of Four was answered by a European Gang of Four, I thought, rather persuasively.

Mr. UDALL. Thank you, Mr. Chairman.

Mr. SCHEUER. Congressman McCain.

Mr. MCCAIN. Thank you, Mr. Chairman.

Mr. Chairman, Mr. Sagan—Dr. Sagan was unable to answer the question that I had. I request that he be allowed to answer for the record as to whether he believes the United States should embark on unilateral reductions of nuclear weapons if negotiatons are failures. I request that he be allowed to answer that for the record.

[See appendix for response.]

Mr. SCHEUER. Without objection, the record will be open for any member to address questions to any of the witnesses or the panelists for inclusion in the record.

Mr. MCCAIN. Thank you, Mr. Chairman.

Thank you, Secretary Perle, for, as always, a very eloquent testimony. You know, I'm also glad you brought up this very unfortunate aspect of what is a very important debate, and that is impugning the motives, the dedication to freedom and peace throughout the world of individuals who are taking opposite viewpoints.

And I might say I think it's very much beneath Dr. Sagan and the outstanding reputation that he enjoys in this country to impugn the motives, the dedication to world peace and the prevention of nuclear war by our President and our negotiating team in Geneva at this time. I believe that this debate is demeaned by doing that, and I believe that it's important that this issue is debated on its merits and demerits rather than the motives of the individuals involved, which I don't believe that any of us are able to ascertain.

My question to you is, Is it indeed true that the Soviet Union has embarked on an SDI of their own?

Mr. PERLE. Yes; it is now and it has been, and that program began to gather momentum after the signature of the ABM Treaty of 1972. The Soviets were the first, as far as we know, to engage seriously in directed energy research, in high-powered laser research. They have an active program. They have the only antiballistic missile system deployed anywhere in the world today, and they are actively working on it to improve it. They have deployed, as you know, a large phase-to-ray radar in clear violation of the ABM Treaty in order to complete the nationwide coverage of the Soviet Union with a long-range radar. They are deploying air defense systems that we believe have significant ABM potential. In short, they have a vigorous program at all levels of science and technology. They are investing sizable sums in it.

You know, 10 days after the President gave his speech in April 1983 on the American Strategic Defense Program, there appeared an open letter in Pravda and reprinted in a number of other places as well, signed by a very large number of Soviet scientists. And in this letter they deplored the perversion of science for the purpose of building the weapons of war. And they also expressed the view which we've heard a couple of times here this morning that SDI couldn't possibly work. We took this list of Soviet signers and we sent it over to the CIA and we said can you look through your files and tell us what you know about these fellows, if anything. And they weren't able to identify all of them, but they were able to identify about half. And among the half they were able to identify is the fellow running the Soviet SDI program, the man who designed the Moscow ABM system, the designer of the Soviet SS-18 ballistic missile, the designer of the Soviet Typhoon class submarine program, and I could go on and on, because every one of the fellows we were able to identify, with a couple of exceptions, was up to his eyeballs in military research and development. The Soviet position on this is built on a really breathtaking hypocrisy.

Mr. McCAIN. Well, to carry a comment you made earlier a little further, the next time we seek a joint project of scientific cooperation with the Soviet Union, particularly where it entails anything to do with nuclear or strategic weaponry, I think we ought to insist on the presence of Dr. Sakharov. I don't know of anyone who would be more qualified in the Soviet Union to partake in one of these joint studies, do you?

Mr. PERLE. I don't. And I must say I have been impressed with the degree to which the American scientific community has rallied around Dr. Sakharov, and I am concerned that that resolve to make the Soviet scientific community pay enough of a penalty so that Dr. Sakharov would be protected. That resolve may be weakening. I hope it's not.

Mr. McCAIN. Thank you.

Isn't it true that the Soviet Union continues to develop and produce unabated—in an unabated fashion chemical and biological weapons of war?

Mr. PERLE. There is no question that the Soviets maintain a very sizable arsenal of chemical weapons. They train in the administration of those weapons. It's an impressive program, and they take it seriously.

Mr. McCAIN. Perhaps then we should have a study concerning the effects—the possible effect on the world of the unleashing of those weapons. Would you recommend that as well?

Mr. PERLE. I think I would be inclined first to see whether we have already done analyses of—of that kind. There is no doubt in my mind that tremendous damage could be inflicted with chemical and biological weapons. And biological weapons are a truly frightening prospect. Whether we need to do original research, I don't know, but we can certainly pull together what we think we know.

Mr. McCAIN. Finally, the Soviet Union is installing new leadership. Do you have any optimism about the possibilities for agreements between ourselves and the Soviet Union, particularly as regards to arms reductions, with the new Soviet leadership, or do you see that it's just business as usual?

Mr. PERLE. I think it is almost certainly the case that Mr. Gorbachev has for some months now been a significant influence on Soviet policy. Whether the Soviets in this round of negotiations will demonstrate a greater willingness to negotiate toward significant reductions, I simply don't know. It remains to be seen.

I know this: They won't do it unless they believe—unless they believe that they cannot get away with a kind of agreement that would be much more to their liking, which would be one of providing possibly even for increases, but in any case, for no significant reduction. So I hope we will have the patience which we've lacked all these many years to hang in there until we can get an agreement that moves us in the direction of solving this nuclear winter problem and doesn't simply legitimize the levels of weapons that Carl Sagan deplores and that I deplore, and I think we all deplore.

Mr. MCCAIN. Thank you.

Thank you, Mr. Chairman.

Mr. SCHEUER. That completes your testimony, Secretary Perle. We want to thank you for appearing before us this morning. And I must say that whether we agree with every jot and title of the administration's policy on arms control and nuclear winter, you certainly are a formidable representative of the administration here, and it's almost—it's an intellectual treat to listen to you as it is to listen to Dr. Sagan. And we hope that both of you will beat your—personally, on a personal level, even before we get to the solution of nuclear arms, that you will beat your swords into plowshares and never study war, interpersonal war anymore. We thank you very, very much.

Mr. PERLE. Thank you, Mr. Chairman.

Mr. SCHEUER. Congressman Udall.

Mr. UDALL. For my colleagues for planning purposes, we have two more panels I think what we'll do is, if we can, get the first panel done in the next 25 or 30 minutes, and then come back at 2 o'clock and finish up the last panel. Unless there's some disagreement on that schedule, we'll follow it.

We will proceed now to the next panel, Dr. Jeremy Stone, Dr. George Rathjens, Mr. Williamson, and Dr. Brode.

Mr. Wirth suggests, and I think I'll follow his suggestion, that because panel 2 only consists of just two additional witnesses, we'll combine all of the panels and give each of them about 5 minutes for summary of remarks and then we'll have questions. So Dr. Carrier and Dr. Schneider, if you'll hold yourselves in readiness, we'll put you on at the end of the panel, this panel. We'll just combine the two essentially.

Dr. Jeremy Stone, director of the Federation of American Scientists. Dr. Stone, we're glad to have you here today. You may lead off.

STATEMENTS OF DR. JEREMY J. STONE, DIRECTOR, FEDERATION OF AMERICAN SCIENTISTS, WASHINGTON, DC; DR. GEORGE RATHJENS, PROFESSOR OF POLITICAL SCIENCE, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MA; DAVID WILLIAMSON, JR., SENIOR FELLOW, SCIENCE AND TECHNOLOGY POLICY, GEORGETOWN UNIVERSITY CENTER FOR STRATEGIC AND INTERNATIONAL STUDIES, WASHINGTON, DC; AND DR. HAROLD L. BRODE, VICE PRESIDENT, STRATEGIC PROGRAMS, PACIFIC-SIERRA RESEARCH CORP., LOS ANGELES, CA

Dr. STONE. Thank you, Mr. Chairman.

I think the committee is struggling to figure out what is the new thing about nuclear winter that surely must be there that implies some change in American policy. And not surprisingly both sides of the debate have readily agreed that the policies they were already urging in this debate are those exactly called for by nuclear winter. This should be no surprise to the Congressmen.

There is one thing new about nuclear winter, I think, that has not been given sufficient weight by the Defense Department. And when Secretary Perle said that nuclear winter is just a war worse than the kind we had anticipated and that it parallels their own understanding of nuclear war, I think he's overlooked one important aspect of it. And that important aspect of it is that the weapons fired at Soviet cities, in some sense, are fired against our own. So where Secretary Perle said that there was always an interest on our part not to target Soviet cities and that there was always a withhold mechanism to prevent collateral casualties, I think he has passed over the fact that nuclear winter provides an entirely new reason for sticking to these withholds, an entirely new reason for not firing missiles at Soviet cities. It's the cities, of course, that have the flammable materials that cause a nuclear winter.

And so I think that the major new immediate policy implication of nuclear winter is of great interest to both sides in avoiding attacks on cities, interests that were there in a much more passive and latent way before. I think this is especially important to emphasize because when the time comes to attack cities by our forces or Soviet forces, the war will be well begun, and we're not even sure who will be the person who will push the button in a war in which some cities have already been attacked and in one country or the other, an extremist decides to fire these final options at cities of the other side. So I think it's very important that the Defense Department review the options in the SIOP with a new eye to the direct American interests in preventing attacks on Soviet cities.

And second, I think the Defense Department is overlooking a new angle that nuclear winter provides to the Department for persuading the Soviet Union not to fire at American cities. In other words, there is now a direct Soviet interest, if they become persuaded about nuclear winter, in avoiding attacks on our cities. And if the Defense Department is really interested in deterrence, this is a new approach to deterrence, which doesn't cost anything and which could save a lot of lives here as well as the planet if, in fact, a few officials in the Soviet Union do become persuaded at the last moment that it would not be in their interest to fire at these cities even once nuclear war has begun.

So while I'm a strong fan of the reductions that Dr. Sagan talked about and an opponent of the star wars and the modernization that the administration talks about, I don't view either of those as immediate responses to nuclear winter because both of those will require a long time to take place.

But a review of the war plans with regard to this new effect of nuclear winter—that attacks on Soviet cities are also attacks on our cities—that there is an important rebound effect, boomerang effect, to attacks on Soviet cities. This is something new. And this should have implications for policy, immediate implications for policy, and those implications should be reflected in much greater restraint in the war plans, and possibly the removal of certain options which I think are not necessary for deterrence but would, in fact, be very counterproductive for us—in particular, options to destroy 250 smaller cities in the 300 largest Soviet cities, things like that.

Mr. Chairman, if there is any more time in my 5 minutes, I would observe—make two observations about Secretary Perle's policy.

[The prepared statement of Dr. Stone follows:]

A/

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*Nobel laureates

NUCLEAR WINTER HEARING

Testimony of
Jeremy J. Stone, Director
Federation of American Scientists (FAS)

Before the

Subcommittee on Natural Resources, Agriculture
Research and Environment of the Committee on Science
and Technology

and the

Subcommittee on Energy and Environment of the
Committee on Interior and Insular Affairs

March 14, 1985
9:30 a.m., Room 2318
Rayburn House Office Building

National Council Members (Elected)
Ruth S. Adams
Harrison Brown
Rosemary A. Chalk
Bernard T. Feld
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Morton H. Halperin
John Harte
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Arthur H. Rosenfeld
Carl E. Sagan
Eugene B. Skolnikoff
Robert H. Socolow
Lynn Sykes
Robert H. Williams
Archie L. Wood
Dorothy S. Zinberg

NUCLEAR WINTER & NUCLEAR STRATEGY

American policy-makers, in this era of nation states, are primarily concerned with the security of the United States rather than with that of the world.

And, in any case, the major threat to both the United States, and to the world, from excessive use of nuclear weapons arises from uncontrollable escalation once nuclear war occurs.

It is these two considerations that have limited the impact of nuclear winter on American nuclear policy. The fear of nuclear escalation and of the consequent destruction of the United States already constitute an enormous restraint on any decision to use nuclear weapons either in Europe or against the Soviet Union itself.

But the prospect that nuclear war might, in fact, endanger the species calls for an intense review of the entire situation--one from which the security of the United States might well benefit but one that should be conducted anyway for the sake of the planet. In other words, nuclear winter has raised the stakes and Congress should review the game.

THE SINGLE INTEGRATED OPERATIONAL PLAN (SIOP)

As part of this review, Congress should be more deeply involved in oversight of the war plan--the Single Integrated Operational Plan (SIOP).

In particular, one does not get the impression from reading the Defense Department's report "The Potential Effects of Nuclear War on the Climate" that the Defense Department has reviewed its plans with nuclear winter in mind.

On the contrary, this Defense Department report is complacent and opportunist in telling Congress that a number of things which it had done earlier (substituting more MIRV warheads for larger ones) or says it wants to do today (Star Wars defenses, nuclear disarmament and small modernized nuclear weapons) happen to be marvelously consistent with protecting against nuclear winter.

In any case, with 20,000 nuclear weapons in the strategic forces of the two sides today, neither any plausible disarmament, nor any foreseeable Star Wars defenses, are going to eliminate the possibility of nuclear winter. What is needed, instead, is the prevention of the use of large-scale attacks from either side.

Therefore, what is striking in its absence is any reference to a new review of the war plans. And to appreciate the significance of this, perhaps some reference to what is known about them is in order. What follows is drawn from the writings of the Australian strategic analyst Desmond Ball.*

The American strategic forces of approximately 10,000 warheads are embedded in a war plan that has 40,000 potential located targets divided into:

1) Soviet nuclear forces: ICBMs, IRBMs, nuclear weapons storage sites, airfields with nuclear-capable aircraft and nuclear, missile-firing submarine (SSBN) bases.

2) Conventional military forces: casernes, supply depots, marshalling points, conventional air fields, ammunition storage facilities, tank and vehicle storage yards.

3) Military and political leadership: command posts, and key communication facilities.

4) Economic and industrial targets: war-supporting industry (e.g. ammunition and tank factories, petroleum refineries, railway yards) and industry that contributes to economic recovery (coal, steel, aluminum, cement, electric power)

The options in the SIOP are further divided into:

1) Major Attack Options
2) Selected Attack Options
3) Limited Nuclear Options (designed to permit the selective destruction of fixed enemy military or industrial targets)
4) Regional Nuclear Options (intended, for example, to destroy the leading elements of an attacking enemy force)

EVEN IF NO ESCALATION IS ASSUMED . . .

For the purposes of analysis, let us assume the unassumable that these American options could take place without escalation--with the Soviet Union either not firing back at all or firing back in some matching fashion with no subsequent round of firing on either side. These are, obviously, the most favorable cases.

Now, even in these very favorable cases, some DOD review should take place of whether the fires resulting from the options might trigger a nuclear winter.

In the case of Soviet nuclear forces, at least 2,000 potential targets exist. Ball has pointed out that many of these targets are located in some of the most densely populated areas in the Soviet Union where, for example, lives lost to blast and fallout could range from 3.7 million to 27.7 million. And, of course, besides fires induced by us, there are the fires created by Soviet attacks on our own strategic forces in response.

The case of attacks on Soviet leadership would certainly involve attacks on cities. While a "relatively small percentage" of the U.S. forces were said by one Congressional witness to be targeted on leadership, only a small percentage of our force, if targeted on sufficient Soviet cities (in many of which some leadership resides) would create potential nuclear winter crises. And, of course, one needs to reflect on the responses from that leadership at least to attack our leadership in its cities (and no doubt much much more in a death spasm).

In the case of economic and industrial targets, we find the most obvious nuclear winter problems. Notwithstanding the disingenuous comments in the DOD report, that the SIOP "consciously does not target population", cities are certainly targeted. In October, 1980, a directive abandoned the requirement that the destruction of 70 percent of Soviet economic recovery and war-supporting assets be the priority mission of American strategic nuclear forces, but Ball observes "it still remains the case that the top 300 urban-industrial areas in the Soviet Union will continue to receive about the same amount of nuclear firepower and to suffer about the same amount of damage."

In other words, the United States, consciously or unconsciously, is targeting the Soviet urban complex. And while there are options for "withhold" of attacks on cities, there is no assertion in the DOD report that this "withhold" has been supported by the imperatives of nuclear winter or reviewed in that light. Perhaps these options should, at the least, be marked by strategic planners as "hazardous for world health" as well as for any Americans who might otherwise survive. Moreover, if these attacks are assumed to give rise to corresponding Soviet attacks, the problem is redoubled.

AND WHAT ABOUT ESCALATION?

The Defense Department recognizes, thought it does not say so in this report, that U.S. command and control is not likely to be, in fact, up to the demanding problem of retaining control over the weapons in such a way as to execute all these options after Soviet attacks have begun. This is a major source of DOD's effort to strengthen command and control.

Very likely, it simply is impossible to achieve the command and control necessary unless the United States fires its missiles first (as has been so often threatened in response to potential conventional fighting in Europe or Korea). Once a few Soviet nuclear weapons go off at the appropriate heights, electromagnetic confusion may dominate and, if Soviet targeting of U.S. command and control assets is assumed—as it should be—then very little can be expected to work for very long.

In any case, even if intra-war command and control were perfect on both sides, escalation would still be likely due to the impossibility for each side of determining promptly and properly what the other side was, in fact, attacking.

Moreover, even if these two problems of control and damage assessment were both completely solved, escalation could be expected for psychological and strategic reasons--as when dogs or humans fight and escalate their fighting even thought command and control and damage assessment are immediate.

Accordingly, those who want to protect the planet from nuclear winter have got to do more than call for the elimination of those SIOP options which, by themselves or in conjunction with comparable Soviet retaliation, would destroy America and the planet.

In addition, they would have to call for the elimination of those options that might plausibly lead to such use through subsequent escalation.

In fact, any single use of nuclear weapons against the Soviet Union--even a single use during a conventional battle in Europe--has a real potential for catalyzing escalation that would go straight to the top of the escalation ladder. Many war games have shown this and the Committee can inquire about it.

As a result, there is a strong case that the Nation should adopt a no-first-use doctrine at least in fact if not in declaratory policy (i.e. in advance). Probably, all of these war plan options should be labeled suicidal for all of us.

Therefore one important role for nuclear winter is to provide an antidote for that optimism which might otherwise infect decision-makers with overriding faith in American technology and its newest command and control gadgets.

In any case, nuclear winter certainly provides Congress with an opportunity and an obligation to review war planning and these options. Congress should be asking with regard to these options: "would even success be failure" and how likely is a "controlled success"?

SOVIET THINKING: AN OPPORTUNITY

The DOD report is scathing in its treatment of Soviet interest in nuclear winter which is portrayed as propagandistic and motivated, perhaps, by a desire for additional access to our super-computers and software model development.

Is not DOD missing a bet here? If nuclear winter can be made persuasive, it might induce the Soviet strategists to review their own war plans. Soviet planners are, presumably, highly interested in perserving their own population. If options it maintains for destroying U.S. cities would, or might, rebound to the destruction of the Soviet population via nuclear winter, this would have to be taken very seriously. In particular, nuclear winter makes Soviet civil defense preparations irrelevant, for example.

Thus, nuclear winter calculations provide America with a way of detering Soviet attacks on U.S. cities. Why not pursue this possibility? It costs nothing.

The Soviet Union, almost certainly, has less sophisticated war plans (i.e. fewer options, less interchangeability of targets, more reliance on mass). What is wrong with trying to persuade them that those of its options that target our cities especially are suicidal even if our forces are, somehow, neutralized in a successful suprise attack.

The Defense Department seems more interested in resisting the idea of nuclear winter at home than in spreading it abroad--more concerned that nuclear winter theories will undermine our defenses at home than that they could have a salutary effect on the targeting of our adversary's weapons on us. Perhaps DOD has lost sight of its goals and is more concerned with protecting business as usual than in defending the Nation in that perceived off-chance that nuclear war actually comes. This would be a mistake.

CONCLUSION

The nuclear winter theory levies on Congress an additional obligation to deepen Congressional oversight into the nature and structure of the Defense Department's war plans (i.e. SIOP options) and its ability to control escalation and to terminate war.

Some of the options may be, even without escalation, and even if executed "successfully", too hazardous in their world-wide collateral effects to justify being maintained as options.

Other options, when considered with regard to the escalation that would likely result, ought be discarded also.

There is important "deterrence" to be gained by pursuing, rather than neglecting, nuclear winter theories. If, as we always assume, the Soviet Union follows its own interests, we ought be broadcasting to it, on all wave lengths, the possibility that its attacks on us, no matter how successful, might boomerang against it. We are trying to persuade them not to fire, are we not?

Finally, it should be emphasized that nuclear winter is not the only theory of widescale collateral destruction arising from nuclear war. The 1975 study of the National Academy of Sciences' entitled: "Long-Term World-wide Effects of Multiple-Nuclear Weapons Detonations" talked not only of the possibility of "a major global climatic change". It also spoke of problems on the ground ("ionizing radiation could cause disease epidemics in crops and domesticated animals on a global scale") and in the oceans (...irreversible injury to the sensitive aquatic species might occur during the years of increase of uv-B following the detonations".)

All of these possibilities have "deterrent" effects. All of them are worth studying. All of them involve risks to our survival and the survival of many other individuals, families and Nations. If the Defense Department were doing its job properly, it would be looking into these matters urgently and with high priority rather than episodically and mainly in response to public pressure.

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*A good treatment of Desmond Ball's work on this subject can be found in International Security, Winter 1982/1983. Ball is a fellow at the Strategic and Defense Studies Centre of the Australian National University and a careful student of the American strategic literature and Congressional hearings.

Mr. Udall. Thank you, Dr. Stone. That's exactly the highlighting type of presentation I wanted.

Dr. Rathjens.

Dr. Rathjens. Thank you. I have a statement here which I'll—I'll not read all of it. I also have another paper which I would hope might be included in the record.

Mr. Udall. It's been distributed to all the members here, I believe, and we would certainly be happy to have it for the official record.

Dr. Rathjens. Thank you.

I want to—I welcome the opportunity to be here, because it seems to me that we need a lot of clarification on this subject. I think the public has been misled, partly by the press, but aided and abetted by the scientific community, I believe, where there have been careless and hyperbolic statements, even irresponsible ones, and I think that needs some correction.

We have heard statements that nuclear winter will occur or would occur when, in fact, it might have been much better if people had said might occur or could occur. We need a correction of that. I even noted that Secretary Perle said that, given enough nuclear weapons, nuclear winter would occur. I don't subscribe to that at all. It's possible, but we have no basis for claiming that it would occur, or even that it is likely.

To a large extent, these prognostications have been based on the TTAPS study, about which you heard. But even at the time that study was done, I think it was apparent that it was at best a first approximation and could only give illustrative answers. Since that time, there's been more work. Particularly, the National Academy has reviewed the state of knowledge, and more recently the Defense Department in the report that was so much discussed this morning.

Two main points come out of those two reviews: One, that nuclear winter could happen; and the other that the uncertainties are enormous and make any meaningful predictions really impossible at this time. Temperatures over continental land masses could drop by 10 degrees and stay that way for weeks or months. But it is just as likely that the effects would be so small that they wouldn't be noticable at all. We just can't say at this time.

Secretary Weinberger's report makes the additional point with which I strongly agree that the work of TTAPS and indeed much of the other work, has been based on omission of effects which, if included, would lead to a lessening of predicted effects. In particular, there has been an omission of the certainty that warm air from over the ocean and from the tropics would infuse over the continents and lead to amelioration of the kinds of effects that have been predicted. A more serious problem is that all of these calculations have assumed that—at least the TTAPS report did—that smoke from fires would spread instantaneously and uniformly over the whole of the hemisphere. That can't happen. It would take time and, during that time, some of the smoke would be removed.

When I take account of these kinds of omissions and all of the uncertainties, it's my judgment that the kinds of effects we are most likely to see would be diminutions in temperature in the range from zero to 5 degrees rather than 10 degrees, as has commonly been suggested.

Now I'd like to turn to questions of how governments should react aside from perhaps supporting more research. And here I'm going to assume for the moment—and I want to make it clear that I'm making this as an assumption—that nuclear winter effects would be severe. There are those doves, nuclear disarmers—I'm one of them—who would argue that great efforts to reduce nuclear stockpiles might be warranted and that we should depend less on nuclear weapons as instruments of policy.

However, I discount those kinds of arguments very heavily because nobody should be misled that nuclear winter's going to make nuclear war much worse for people of NATO and the Warsaw pact. Any war that could conceivably produce serious nuclear winter effects would be utterly catastrophic in any case. For the fellows in the trenches, the people out in Omaha who have to worry about targeting weapons, and the SIOP and that sort of thing, there are kinds of consequences that might—that might be reflected in their work if nuclear winter is taken seriously. One might expect greater emphasis on improving accuracy of weapons delivery, on replacing those of high yield with those of lower yield, on fusing weapons for surface rather than air bursts, even recognizing that that change would lead to more in fallout. And all of these changes, except possibly just improving accuracy, could imply a larger stockpile of weapons. Those kinds of tradeoffs would have to be faced if nuclear weapons—nuclear winter were taken seriously.

It has also been suggested that the prospect of it would induce greater caution, at least in the spring and summer, in military operations that might lead to escalation that could result in nuclear war. But there is the other side of the coin. There could be a greater impetus to use nuclear weapons on a limited scale based on the belief that the nuclear winter prospect could deter further escalation. I discount those arguments, but they are the kinds of logical arguments that I think follow if one believes that the phenomena should be taken seriously.

Then there are the arguments of the administration, and we've heard some of those—heard about some of those this morning, that the prospect of nuclear winter justifies increased support for weapons programs that it claims will reduce the likelihood of nuclear war or will lead to arms reduction. And there is the argument that nuclear winter makes the case for a strategic defense initiative more important.

I think these arguments are logical, but they're based on false premises. I don't think there's any reason at all to believe that going ahead with the new Weapons Programs that the administration advocates are going to reduce the likelihood of war, or lead to substantial arms reductions. And I don't believe there's the slightest hope of going ahead with the strategic defense initiative leading to a situation where fewer nuclear weapons would be detonated in the United States should a nuclear war occur.

Mr. Udall. We'll have to cut you off here shortly.

Mr. Rathjens. All right. Let me just make my last point then, that it does seem to me that, in facing up to this question of policy, one has to take into account the possibility that any changes that one might make to alleviate the effects of a possible nuclear winter would carry with them costs. There is no free lunch in this business. Those costs have to be faced. And in view of the uncertainties that obtain at this time with respect to the nuclear winter phenomena, it seems to me that any changes in policy by the Government of the United States—or for that matter, by other governments—would be premature.

[The prepared statement and article of Dr. Rathjens follow:]

Statement by

George Rathjens

before the

Subcommittee on Natural Resources, Agriculture Research and Environment
of the
Committee on Science and Technology
and the
Subcommittee on Energy and Environment
of the
Committee on Interior and Insular Affairs

March 14, 1985

I have a statement which I would like to read. Rather than preparing a longer version, I would like to submit for the record a short commentary I and one of my students wrote last fall for the new National Academy of Sciences publication, Issues.

I welcome the opportunity to join with you in this discussion of "nuclear winter", particularly because clarification about the nature, likelihood and implications of the phenomenon is most sorely needed. This is because reporting has been egregiously bad, abetted, I am sorry to say, by some careless and hyberbolic, even irresponsible, statements by some members of the scientific community. Thus, the public, and I dare say many members of Congress, have been led to believe that in the event of a large scale nuclear war there would develop a pall of smoke and dust that would spread over much of the northern hemisphere--perhaps all of it and possibly extending even into the southern hemisphere as well—and that this would so reduce the incidence of sunlight at the earth's surface that the result would be sub-freezing temperatures for at least weeks over large areas, even in the event of a war's occurring in summer. There would be dramatic changes in weather patterns, massive crop failures and destruction of biological species, including possibly man. Much of this could happen, but there is no basis for claiming that it would happen or even that it is likely.

To a large extent such dire prognostications have their bases in a study reported in Science magazine in December 1983, now commonly referred to as the TTAPS study after the initials of its authors. It was a pioneering effort deserving of great credit, but it was apparent at the time that because of the uncertainties in critical assumptions and simplifications in modelling, its estimates of diminution in temperatures could only be regarded as illustrative.

Since the publication of TTAPS, much additional work has been done, and the National Academy of Sciences and, more recently, the Department of

Defense, have reviewed the state of knowledge about the phenomenon.*, ** Two points from these reviews deserve to be highlighted: (1) "nuclear winter" could happen; (2) the uncertainties--only some of which are likely to be resolved or significantly narrowed in the next few years—are so many and so large as to preclude making meaningful predictions about its seriousness. Temperatures over continental land masses could drop by tens of degrees and remain well below normal for weeks or months but just as plausibly the effects could be within the range of normal year to year variations, i.e. so small as to be scarcely noticeable.

Secretary Weinberger's report highlights the additional point, with which I strongly agree, that there are a number of problems in the TTAPS work that mean that its estimates of effects should be much reduced. To give but two examples, TTAPS assumes that smoke from fires initiated by nuclear war is spread instantaneously and uniformly over the whole of the northern hemisphere, when, in fact, such spreading would likely take weeks, during which much, albeit a highly uncertain fraction, of the smoke would be removed, and it does not take account quantitatively of the warming effect on continental land masses of the movement of air from over the oceans and from the tropics. Correcting for such omissions would lead to several fold reductions in the magnitude of effects estimated in TTAPS. When corrections for such deficiencies are compounded with the many other sources of uncertainty that are important in estimating "nuclear winter" effects--the amounts of smoke produced, its soot content, the height to which it rises, and its persistence, and with those associated with the circulation of air masses--I believe that diminutions in temperature are likely to be in the range of zero to five degrees centrigrade, not tens of degrees, as TTAPS and some other reports suggest. But above all, I would emphasize that the problem of estimating the seriousness of "nuclear winter" is completely dominated by uncertainty.

I should like now to turn to the questions of how governments should react to the "discovery" of "nuclear winter", aside from perhaps supporting research which might reduce the range of uncertainties about it. Let me assume for the moment that the effects would be as serious as those suggested in TTAPS.

Doves and nuclear disarmers--and I count myself among them--would argue for great efforts to reduce nuclear stockpiles and for less dependence on nuclear weapons as instruments of policy, even if the price were greater dependence on conventional arms. But believing we should be moving in these directions anyway, I discount the argument very heavily. No one should be misled that "nuclear winter" is going to make nuclear war a much more horrifying prospect for people of the NATO or Warsaw Pact countries than it would be, nuclear winter aside. Any war that could conceivably produce serious nuclear winter effects would likely be utterly catastrophic in any case.

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* Committee on the Atmospheric Effects of Nuclear Explosions, Commission on Physical Sciences, Mathematics and Resources, National Research Council, The Effects on the Atmosphere of a Major Nuclear Exchange, National Academy Press, Washington, D. C., 1985

** Secretary of Defense Caspar W. Weinberger, The Potential Effects of Nuclear War on the Climate, A Report to the United States Congress, March 1985

For many others, including most of those responsible for military planning and operations and for various aspects of our nuclear weapons programs, acceptance of "nuclear winter" as a significant consequence of nuclear war could have other effects. One might expect greater emphasis, on improving the accuracy of weapons delivery, on replacing those of high yield with those of lower yield, on fuzing weapons for surface rather than air bursts, even recognizing that the last change would mean more fall-out, and that all these changes--except possibly the first--might imply a larger stockpile. It has also been suggested that the prospect of nuclear winter would induce greater caution--at least in the late spring and summer when "nuclear winter" effects would be most significant--in military operations that might lead to escalation to "nuclear winter" levels. But there is the other side of the coin: there could be a greater impetus to use nuclear weapons on a limited scale, based on the belief that the "nuclear winter" prospect would help deter escalation. (I would discount both of these arguments.)

Finally, there are the arguments of the Administration, exemplified in Secretary Weinberger's recent statement, that the prospects of "nuclear winter" justify increased support for weapons programs that it claims will reduce the likelihood of nuclear war and/or will led to arms reduction. Additionally, the Administration has suggested that "nuclear winter" makes its Strategic Defense Initiative more important. I buy the logic of these arguments, but I do not buy the Administration's conclusions because I do not buy its premises. It is unlikely that going ahead with its various weapons programs will make nuclear war less likely or lead to significant arms reduction--I think quite the contrary--and there is not the slightest reason to believe that the SDI would lead to fewer weapons landing in areas where fires might be ignited. Again, the result is likely to be quite the contrary: each side is likely to over-react to its adversary's defense initiatives, the net result being more offensive weapons on both sides and probably more delivered in the event of war than if the defense initiatives had not been undertaken in the first place. (This leads to a general observation about Secretary Weinberger's report: good as the first two sections are, the last is most unsatisfactory, and, as I understand it, not responsive to the Congressional request which led to it.)

My last point: how should the governments of nations not likely to be directly attacked react to the prospect of "nuclear winter"? Many might hope to escape the effects of a NATO-Warsaw Pact nuclear war relatively unscathed but for the possible effects of "nuclear winter". For them, hedging against "nuclear winter" through the stockpiling of food and fuel and the provision of adequate shelter could make a lot of sense--a lot more for them than for the United States or the Soviet Union--provided "nuclear winter" seemed severe and reasonably likely. But there would be a cost in such hedging, just as there is in buying any other kind of insurance, and the cost may be an excruciatingly painful one to bear for many of the poorer countries of the world—a cost not worth paying if there is just a remote chance of severe "nuclear winter".

I am driven to conclude that when account is taken of the uncertainties that attach to the "nuclear winter" phenomenon and the likelihood that the most popular estimates are greatly exaggerated, policy changes by any government based on it would be premature. Certainly, it would be unwise to take actions simply on the assumption that it is prudent to assume the worst. That would be all right if there were no cost to be incurred in doing so, but that is not the way of the world.

NUCLEAR WINTER: Strategic Significance

[*] The article below is one of several appearing in the Winter, 1985 Issues in Science & Technology Published by the National Academy of Sciences.

George W. Rathjens
Ronald H. Siegel

Is nuclear winter a likely consequence of nuclear war?[1] Is it even plausible? Should policy be based on worst-case analysis of the possibility? These are some of the questions we address.

There is a widespread impression, at least among readers of newspapers and general periodicals[2] in the United States, that a large-scale nuclear war in which cities would be heavily attacked would trigger a nuclear winter. These periodicals suggest that burning cities would create a heavy pall of smoke that would spread over[**] a large fraction of the earth—at least over the northern hemisphere—and that this smoke would absorb most of the radiation that the earth normally receives from the sun. As a result, temperatures would be tens of degrees below normal for months. Those who survived the immediate attack would face the climatic and ecological disruptions of this nuclear winter. There are suggestions, in at least some of these publications, that because a number of research groups have reached quite similar conclusions about the temperature changes predicted to follow a nuclear war, those conclusions are robust.

On the other hand, a careful reading of the scientific paper on which almost all of the more popular American presentations have been based—the Turco, Toon, Ackerman, Pollack, and Sagan (or TTAPS) paper—and its companion piece[3] gives a different impression. A critical examination of the TTAPS paper makes clear that there are enormous uncertainties in its assumptions, and that the model on which the conclusions are based is woefully inadequate. This impression is strongly reinforced by a reading of other relevant technical literature.[4]

Similarly, the recent National Research Council (NRC) study, *The Effects on the Atmosphere of a Major Nuclear Exchange*, highlights the uncertainties surrounding the question of nuclear winter, making clear that conclusions about it are anything but robust. The NRC committee concluded that insufficient evidence exists to determine how much temperatures would drop at the earth's surface following a nuclear attack, although they do report the results of various modeling efforts that place the maximum surface temperature reduction at 11 to 42 degrees centigrade. Our view is that the climatic effects of nuclear attacks are *very* uncertain—and most probably much less severe—than those cited in the NRC report.

[**] This was a misprint. The word "over" should have read "of".

Some of the literature has suggested that nuclear war would also result in quite large climatic and ecological effects in the southern, as well as the northern, hemisphere, and it has even been suggested that nuclear winter could lead to the extinction of mankind. We believe there is no basis for the last speculation and very little for the former.

It is striking that many thoughtful people who concede that there are enormous uncertainties in the estimates of the climatic effects of nuclear war argue nevertheless that in the absence of definitive refutation, simple prudence should dictate that individuals and governments act as if nuclear winter were probable. We argue that individual and public policy views should be based instead on a best estimate of the probability and severity of nuclear winter effects, taking into account all the attendant uncertainties.

II

To determine whether or not speculation about nuclear winter should be taken seriously, one must have some understanding of the nature of the models on which the estimates of climatic effects have been based and of the uncertainties surrounding the critical parameters of those models. A detailed critique of the major nuclear winter studies is beyond the scope of this paper, but some general comments will suggest the nature of our reservations.

Depending on the particular scenario used for a nuclear attack, forests and woodlands would burn, releasing a great deal of smoke. Ground-burst weapons would also generate a great deal of dust that would be dispersed into the atmosphere. However, the main contribution to nuclear winter (if it is to occur at all) would come from the burning of cities, at least for the type of attacks that has been most emphasized. For that reason, we will focus on the smoke from burning cities. The seriousness of the nuclear winter effect will depend critically on the amount of smoke produced, on its optical properties (only quite sooty smoke will absorb solar radiation effectively), on its persistence (which will depend on the height to which it rises), and on how rapidly it spreads in horizontal directions.

The amount of smoke produced when a city burns will vary enormously, depending on the density of combustible materials (compare, for example, Dallas and Phoenix with older cities in the eastern United States or in Europe) and how completely they burn. The soot fraction in the smoke will depend critically on whether the fires are well ventilated; on the ratio of asphalt, polymers, and flammable liquids to cellulosic fuels; and notably, on how completely the asphalt burns. On the basis of an analysis of the amount of fuel available and a review of the literature relating to combustion, we believe that that there would likely be about four times less smoke and eight times less soot than, for example, the NRC assumed as a basis for calculations. However, there remain significant uncertainties in all these factors, both in our estimates and in those of the NRC. In addition, we believe that the models have overestimated the height to which smoke would rise.[illegible] For many cities, as for forests, the rate of energy release from fires may not be sufficient to drive smoke to altitudes of about four to ten kilometers and above, where it would persist long enough to have significant effects. Whatever the amount and altitude, smoke will be removed as a result of scavenging by rain and vertical diffusion. The rate of removal, however, is very uncertain. There are strong arguments for both less and more rapid removal than under normal conditions.

In short, we strongly believe that the chosen parameters that relate to the production of smoke—and in particular, of soot—and to its vertical distribution and persistence have been such as to seriously overestimate the effects of nuclear winter.[6]

In addition, other deficiencies and omissions in the TTAPS and NRC studies also contribute to this overestimation of effects. The most serious problems, which are well recognized in both studies, arise because it is very difficult to model the three-dimensional flow of air masses.[7] Instead of doing so, it has been assumed that smoke and dust are spread uniformly and instantaneously over the area of interest (the northern hemisphere in the TTAPS paper and the region from 30 to 70 degrees north in the NRC report), and that heat flows only in the vertical direction. Thus, the models fail to take into account the movement of warmer air masses from south to north and from oceanic to continental areas, particularly to their western edges. As a result, the average cooling over the continents could be much less—perhaps by a factor of two—than calculated.

In addition, smoke will *not* spread instantaneously over the hemisphere or the 30-to-70-degree band, as is assumed. Rather, it is likely to be weeks before anything approaching a homogeneous distribution of smoke over these large areas is attained. During that interval of patchiness, the effect on heat flow to the earth will be much less than is estimated by one-dimensional modeling, as open areas would receive their normal sunlight.

These deficiencies and omissions in the various models lead us to suggest that nuclear winter is more likely to be characterized by average changes in temperature over continental masses in the range of zero to five degrees rather than by the predicted changes of 10 to 40 degrees centigrade, and above all, that all estimates must be treated with great reservations. This is not to criticize all of the work that has been done. Some studies have been excellent; some of the limitations have been recognized; and *in the scientific publications*, the conclusions have generally been appropriately qualified. But we are troubled when we hear or read in the popular press accounts of nuclear winter that magnify its severity and that give it an aura of inevitability.

III

How should individuals and governments react to the possibility of nuclear winter? We address the question first from the perspective of the individual. Should attitudes about nuclear war change? For some Americans, the answer will presumably be: "Not much." According to existing models, a nuclear war serious enough to cause nuclear winter would almost necessarily destroy most of our large cities, and with them, our whole social infrastructure and a large fraction of our population—quite possibly more than 50 percent. (The Office of Technology Assessment has estimated destruction of 88 percent of the population from a very large attack.[8]) From this perspective, nuclear winter would appear to be of slight significance compared with the larger catastrophe of nuclear war. In contrast, there are other individuals in the United States and in countries that would probably not be directly attacked for whom the prospect of nuclear winter may be truly horrible: it could mean the destruction of nations and death of hundreds of millions—possibly billions—of people who might otherwise survive a nuclear war.

We turn now to the questions of how governments might react to the prospect of nuclear winter and whether they should base their reactions on the worst possible effect resulting from a nuclear exchange or on some more realistic estimate. Consider first the governments of the United States and the Soviet Union. For each government, the other consequences of nuclear war would probably dwarf the effects of nuclear winter on its own country—even assuming that the more dire prognostications about nuclear winter were true. Hence, there is little reason to believe that they would be much more disposed to reduce or control their nuclear capabilities than they were absent the prospect of nuclear winter. Nor would it seem likely, considering their records, that they would do so out of consideration for—or in response to pressure from—other nations. It is perhaps more likely that they would make changes in their weapons stockpiles, in their allocation of weapons to targets, and in their actual use of weapons. Specifically, we might expect:

(1) Some forbearance in attacking secondary targets, to limit the extent of urban fires.
(2) Some impetus in the short term to fuze weapons for lower burst altitudes[a] and perhaps in the longer term to develop earth-penetrating warheads.
(3) Even greater emphasis on development of better guidance systems, including maneuvering reentry vehicles, so that important targets could be destroyed with smaller yields and hence less likelihood of causing large fires. There could well be an increase in total weapons requirements.
(4) Greater emphasis on air and ballistic missile defense of cities.
(5) Diminution in the willingness of each superpower to execute in the summer a nuclear attack of a scale that might cause nuclear winter. (The effect of smoke on climate and crops is expected to be much less for a nuclear war occurring in fall or winter rather than in summer.)
(6) Increased propensity to use nuclear weapons in limited and selective ways—that is, for "nuclear warfighting"—because the prospect of nuclear winter would help to deter escalation. (Again, the effect could be expected to be seasonal, relevant mainly in spring and summer.) We should note here that we cannot imagine the political leaders of either the Soviet Union or the United States acting on the assumption of a *well-defined* limit on the number of nuclear weapons or total yield that could be "safely" used, or on the number of cities that could be "safely" attacked.

A question should be raised about the consequences of an asymmetry in perceptions about nuclear winter. If, for example, the leadership of the United

States believed that the effects would be severe while Soviet leaders did not, could this be exploited?[10] In principle, of course, it could: in any competition, the "non-believing" nation (here, the Soviet Union) would have an advantage in that it would be willing to escalate the war—even to a level that believers feared would produce nuclear winter. But, in fact, the advantage would be infinitesimal, and we would discount it, just as we would the arguments in (5) and (6) above: the added consequences of nuclear winter are just not likely to loom very large in the minds of the leadership of either superpower compared with the direct consequences of nuclear war.

The situation would be radically different for the leadership of those countries that would probably not be directly attacked during a nuclear war between the superpowers. For many, nuclear winter (if severe) could mean the difference between total disaster and survival with little damage. Could they—should they—do anything to avoid or alleviate disaster? Many countries would have the possibility of greatly reducing suffering if they were to stockpile food and fuel and to provide adequate shelter for the population. People do, after all, live through long, cold, dark winters with no great difficulty, *if* they are prepared. Thus, such provisions might make sense—more for neutral countries than for nations that would be directly attacked. But stockpiling could in some countries require considerable sacrifices. These would likely be especially painful for most of the countries for which such provisions would be most effective—that is, for the Third World countries in the northern hemisphere that would be covered by smoke. We would argue that this difficult trade-off should be based on the *best estimates* of the likelihood and severity of nuclear winter effects, with as full an appreciation of the uncertainties as possible. It should *not* be made on the basis of the possibility that nuclear winter cannot be excluded. Such a criterion—the impossibility of exclusion—is simply not useful as a basis for hedging against catastrophe when there are real costs associated with such hedging.

We would generalize and argue that the whole question of nuclear winter should be approached from such a perspective: that it is a grave mistake to argue that it is prudent to base policy on the worst possible effects of a nuclear exchange, given the large uncertainties. ■

NOTES:

1. The work on which this article is based has been supported in part by the Carnegie Corporation (GWR) and the Levinson Foundation (RHS).
2. C. Sagan, "Nuclear War and Climatic Catastrophe," *Foreign Affairs* (Winter 1983/84); C. Sagan, "The Nuclear Winter," *Parade*, October 30, 1983; C. Sagan, "We Can Prevent Nuclear Winter," *Parade*, September 30, 1984; A. Ehrlich, "Nuclear Winter," *Bulletin of the Atomic Scientists*, April 1984; R.P. Turco et al., "The Climatic Effects of Nuclear War," *Scientific American*, August 1984.
3. R.P. Turco, O. B. Toon, T.P. Ackerman, J.B. Pollack, and C. Sagan, "Nuclear Winter: Global Consequences of Multiple Nuclear Explosions," *Science*, December 23, 1983, 1283-92; P.R. Ehrlich et al., "Long-term Biological Consequences of Nuclear War," *Science*, December 23, 1983, 1293-1300.
4. C. Covey, S.H. Schneider, and S.L. Thompson, "Global Atmospheric Effects of Massive Smoke Injections from a Nuclear War: Results from General Circulation Model Simulations," *Nature*, March 1, 1984; E. Teller, "Widespread After-Effects of Nuclear War," *Nature*, August 24, 1984; R.P. Turco et al., "'Nuclear Winter' To Be Taken Seriously," *Nature*, September 27, 1984; J.J. Barton and G.W. Paltridge, "'Twilight at Noon' Overstated," *Ambio*, Vol. 13, No. 1. (The title refers to an earlier paper by P.J. Crutzen and J. Birks, "The Atmosphere After a Nuclear War: Twilight at Noon," *Ambio*, Vol. 11, Nos. 2-3, which was the primary impetus for the flurry of interest in nuclear winter). See also P.J. Crutzen, "Darkness After a Nuclear War," *Ambio*, Vol. 13, No. 1, a response; S. L. Thompson et al., "Global Climatic Consequences of Nuclear War: Simulations with Three Dimensional Models," *Ambio*, Vol. 13, No. 4; M.C. MacCracken, *Nuclear War: Preliminary Estimates of the Climatic Effects*

of a Nuclear Exchange, Livermore report UCRL-89770, October 1983; P. Crutzen, I. Galbally, and C. Bruhl, "Atmospheric Effects from Post-Nuclear Fires," *Climatic Change,* Issue 6, 1984.

5. The National Research Council (NRC)'s calculations have been done using a model based on point sources rather than on area sources. Moreover, while the effect of wind on plume height is recognized, the calculations have been done for no wind.

6. Given the current state of knowledge, any values selected for the critical parameters that determine soot loading must be regarded as highly uncertain. The effects of uncertainty on temperature at the earth's surface are highly nonlinear. A several-fold reduction in soot loading from the NRC values would require a dramatic scaling down in maximum temperature reduction, whereas a several-fold increase would have almost no effect on maximum temperature reduction (although it could have a significant effect on the duration of nuclear winter).

7. Two studies have treated three-dimensional flows: C. Covey et al. and M. MacCracken (note 4).

8. *The Effects of Nuclear War,* Office of Technology Assessment (Washington, D.C.: Government Printing Office, 1979).

9. While such a development might reduce the incidence of fires, it would increase fallout.

10. Mark Johnson, personal communication.

Mr. UDALL. Thank you.

Mr. Williamson.

Mr. WILLIAMSON. Thank you, Mr. Chairman. I'll be very brief.

Almost everything that can be said seems to have been said, perhaps with one exception, and that is that we haven't talked about the basic interests of the United States or the Western Alliance in this entire environment that we're talking about today.

If we come to a conclusion that the geopolitical balance is not going to change whether or not nuclear winter turns out to be at some threshold of detonation a real threat, a maybe threat, a sometimes threat, if we can keep our eye on that target, which is how to contain aggression, how to contain the entire Soviet-Western conflict of ideology, economics, and so forth, at a noncombatant level, then I think we will have taken a major step forward. Deterrence, after all, is a belief that the consequences of some action are inexorable and unacceptable. We may find ourselves in a very strange trap where we believe that certain actions go in that group—direction, others do not.

And I think that to try to tailor policies that look toward less sooty targets, to use a shorthand phrase, is not wise. I think that in trying to solve with facts and precision—America's desire to always deal in detail—is to avoid solving the major problem, which is, are you going to be in a position to deter the other side and anyone else from starting the initial detonation. Once that has happened, once that first detonation has occurred, I suspect escalation, the rule of the jungle, will obtain and whether it's a nuclear winter or not, it will be nuclear devastation beyond belief.

For the urge has to be to stick to the deterrent side of that issue, and, frankly, people keep saying SDI is not a deterrent. I think that a good defense, the existence of a good defense, weak though it may be, is enough to put uncertainties in the attacker's mind that reduce his desire to start a war, whether there's a nuclear winter component or not. And I think that we ought to try to put things in a perspective of national will, national survival, not after war, but by avoiding that war.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Williamson follows:]

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Center for Strategic & International Studies
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B/

STATEMENT OF DAVID WILLIAMSON, JR.

SENIOR FELLOW IN SPACE AND TECHNOLOGY POLICY

GEORGETOWN UNIVERSITY CENTER FOR STRATEGIC AND

INTERNATIONAL STUDIES

before the joint session of the

SUBCOMMITTEE ON NATURAL RESOURCES, AGRICULTURE RESEARCH

AND ENVIRONMENT of the

COMMITTEE ON SCIENCE AND TECHNOLOGY

and the

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT

of the

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS

March 14, 1985

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March 10, 1985

OUTLINE OF POINTS

1. Debate has focused on whether theory is correct and, if so, at what levels and to what extent

2. One perpsective suggests that one school hopes to disprove theory to "allow" nuclear conflict, another to prove it to "disallow" such conflict.

3. Full range of environmental effects cannot be demonstrated or proven; short of a test, all sides will have to be satisfied with beliefs of a varying intensity as to the outcomes of various target/weapon interactions.

4. New political/strategic factors are introduced by the theory, some independent of its refinement through further research, others dependent on precision:
   - o can threshold be predicted that allows one-way strike but no response?
   - o can hostililities that avoid sooty targets be considered "safe"?
   - o will concern with environmental backlash lead to emphasis on different nuclear weapons, tactics, and targets?
   - o will belief be disproportionate among the nations, leading to distortions of percieved power and inherent international instability?
   - o will U.S. public perception create a populr myth that then forces public policy?

5. Nuclear war -- limited or total, counterforce or countervalue -- seems terrible enough to need no further rationale for avoidance. If nuclear winter acts to increase self-deterrence, then its putative existence helps dampen threats of war. Conversely, if it is theoretically proven not to exist, the preexistent penalties of nuclear war are not reduced -- but attitudes may mistake the absence of one evil for the absence of many.

6. It seems that a global recognition of the environment's fragility and of the self-destructive character of nuclear hostilities should
   - lead to emphasis on defense at the expense of offense in the next generation of force structure design
   - lead to greater emphasis on non-nuclear weapons by all parties
   - lead toward a regime of nuclear reductions

7. It seems that, at least today, the USSR has not accepted the theory to the point of altering force structure but is ready to use the public impact of nuclear winter in pursuit of the political aim of fractionating Western consensus.

8. Whether right, sometimes right, or wrong, the nuclear winter model of nuclear hostilities outcomes is not likely to affect the basic geopolitical concern of the Western alliance -- how to contain an aggressive, expansionist USSR. The model may lead to shifts in the tools of national power but not in the need for them. And deterrence will continue to rely on a conviction that the price of aggression is too high, whatever currency at play.

Mr. UDALL. Dr. Brode.

Dr. BRODE. Thank you, Mr. Chairman. I would certainly agree with Professor Sagan that our nuclear policy is surrounded by uncertainty, and I guess we all can agree with Secretary Perle that nuclear devastation is deplorable.

But I think one feature which has not been stressed here is the reason for nuclear weapons in the first place, why they were invented and why they have proliferated, because I believe in that as a clue as to our way out of this dilemma. In World War II we used nuclear weapons at the end. We spent a great deal of time building bombers and manning them with crews and dropping bombs in the millions, ultimately dropping fire bombs in the tens of millions, in order to destroy 70-some German cities and 65 Japanese cities, the last two of which were burned using nuclear weapons, a yield smaller than any of our nuclear arsenals today of our strategic weapons. Obviously, the nuclear weapons were far more efficient, more effective at achieving a military goal and, therefore, were at least welcomed in a military sense.

In the long run, what we need to look for, of course, are more efficient ways of achieving—or equally efficient ways of achieving military goals without the attendant mass destruction, because nuclear weapons, as well as chemical weapons, are essentially weapons of mass destruction or large area weapons.

I see that then as the promise of decades in the future of high technology, of weapons which are of such great accuracy that they don't need large yields to achieve their military goal of destruction, high probability of destruction of some target. Of course, there will be some targets which are very hard or are characteristically area targets that still may be more effectively attacked with nuclear weapons, but surely with the advent of more sophisticated weapons, we could look forward to an era in which nuclear weapons were not as important an aspect of our weapons arsenal.

In the meantime, in the decades between now and such time when we have less dependence on nuclear forces, our principal objective, I suppose, is to avoid war and to minimize the effects on the short term. Dr. Rathjens mentioned a good many of the short-term kinds of solutions that we might achieve. I might just add one more, and that is the use of the nuclear weapons that would penetrate the Earth before detonation. The Earth-penetrating weapons would then be of smaller yield, cause enormous disruption within the target area, but have less so-called collateral damage beyond that target area, cause less blast damage, less—smaller fire areas and, therefore, contribute less to the smoke load in the atmosphere which would then lead to the nuclear winter phenomena.

Let me say just a word about the research program as it is structured. Recently DNA had a conference on the nuclear winter research in which most of the researchers in this country and some from abroad discussed what they have done, why they are doing and what they plan to do in—principally on the matter of the nuclear winter, the generation of the smoke, where the smoke goes, what the atmospheric consequences are. It was not a meeting which discussed biological effects or sociological effects.

My impression was that the many factors that were discussed at that meeting are of the nature of mitigating factors that could lead to less of a dramatic effect as the earliest estimates would suggest. Nonetheless, some of the factors could lead to more serious consequences, and the matter of uncertainty certainly was stressed at that time.

I think that program is certainly worthwhile. It has some additional beneficial factors, which is certainly of secondary importance considering the seriousness of this problem. But unlike some applied military research, it certainly is some benefit to climatological research, weather research, to high altitude physics studies and to fire research in the work that is currently going on.

[The prepared statement of Dr. Brode follows:]

UNCERTAINTIES IN THE GLOBAL CONSEQUENCES OF NUCLEAR WAR AND THEIR IMPACT ON STRATEGIC POLICY

Based on Testimony by Harold L. Brode, Ph.D.

Before a joint hearing of the Subcommittee on Natural Resource,
Agriculture Research and Environment of the Committee on
Science and Technology and the Subcommittee on Energy and
Environment of the Committee on Interior and Insular Affairs.

Thursday, 14 March 1985

Pacific-Sierra Research Corporation
Los Angeles, California

Forty years of living with the reality of nuclear weapons and the growing capabilities for worldwide death and destruction has lead most thoughtful persons to deplore the existence of nuclear weapons and to seek means for limiting their spread, freezing their production or (eventually) eliminating them altogether. Because of the unprecedented devastation that can be called down upon much of the civilized world within minutes, most of us would rank the avoidance of nuclear war and the elimination of nuclear threats as one of the more important goals to which we can aspire.

While being open to any proposal for limiting the arms race, for freezing nuclear weapons production and development, or for disarming ourselves or other nations, we would do well to consider how we got into such a deplorably fragile and potentially unstable predicament. The first nuclear weapons were conceived and developed to accomplish the military objectives of World War II more effectively. At the time, we had built tens of thousands of airplanes, trained hundreds of thousands of crewman, to carry millions of bombs to German and Japanese cities and other military targets. The cities of Hiroshima and Nagasaki, almost the last to be attacked, were each destroyed by a single bomb dropped by a single B-29 bomber. The damage in each case was impressive although far less than that caused six months earlier by the first big raid against Japan that destroyed a large fraction of Tokyo-Yokahama. The effectiveness, measured in military expenditure of men and materials, was far higher for the two nuclear sorties, however.

The subsequent proliferation of nuclear weapons can be blamed solely on their greater effectiveness. No other means of achieving strategic objectives was then, nor has since to be as reliable, easy to deliver, unequivocal in its destruction or as inexpensive. It is distressing that, as yields and numbers of weapons grew, a great deal of damage was contemplated that was not of particular significance to military goals. For this reason, some rethinking of strategic objectives has taken place. However, the principal remains: any meaningful plans to assert military power on an international scale requires the employment of the most effective weapons available, which currently must mean nuclear weapons. Nuclear warheads exist and have vastly multiplied in numbers and weapons applications because they are by far the most effective means of accomplishing military objectives.

There are two obvious alternatives to explore: (1) re-examine and possibly alter our military objectives, or (2) find other means (equally or more effective) by which to meet the strategic needs. While we can debate our own military objectives, we can not count on altering the nuclear forces of other nations nor changing their planned employment. At best, we might change the planned use of our nuclear weapons and work to coerce the Soviets to make similar changes. That is the hope behind most proposed nuclear arms agreements or negotiations.

But is it possible to find non-nuclear means of satisfying strategic objectives that could rival the effectiveness of nuclear systems? Are there alternative weapon concepts that do not involve widespread devastation?

The universal desire to avoid nuclear war may be eventually satisfied by "high technology". With sophisticated sensors and highly accurate guidance mechanisms, weapons of the future may find their targets with such precision that a high probability of damage can be assured without the use of nuclear warheads. Thus, the widespread death and destruction may be avoided or minimized, and the added issue of global climatic changes due to nuclear war may become less imperative.

Such highly accurate terminally guided or homing weapons can be built with current technology, but will take a decade or two to become an integral part of the military equipment employed in strategic systems. While most urban-industrial targets and many military targets will be vulnerable to attack by such highly accurate warheads, there is a class of well-protected military or leadership targets that may not be damaged without the use of nuclear warheads. (Ultrahard missile silos and buried bunkers may be in this class.) Deep Underground facilities, however, may be able to withstand even the largest practical nuclear weapons. Such deep-buried installations, then, may not be attractive targets for direct nuclear attack at all.

Aerospace and defense industries around the world are already at work developing smart warheads. Terminally guided map followers, stealth or "undetectable" delivery vehicles, armor penetrators and earth burying missiles are being tested. Multi-munitions with many individual target-seeking warheads along with sophisticated target designators all are part of existing or the coming arsenals. Already in application are selective sensors that can detect certain vehicles or passing people and detonate a buried explosive. These developments all promise greater effectiveness against a variety of targets, and are well on the way to being integrated into modern weapon systems.

Even more fantastic and more effective weapons lie ahead a decade or so in the future. Science fiction writers prove to be more reliable prognosticators of weapons developments than the most knowledgable engineers and scientists. The fiction writers identify what would be most effective, and ignore the practical difficulties of inventing such weapons. Engineers and scientists closest to the work are most impressed with the unsolved problems and the difficulties in developing new devices, and so are more prone to provide reasons why significant new inventions are unlikely or impossible. Science fiction writers conjure up the personal weapons--the "bullet" with your name on it, the remote-controlled aor self-guided weapons capable of crawling or flying inside vital equipment or protected structures, smart mines that can lie in wait for a specific vehicle or individual outside the confines of some facility. As these high technology alternatives become realities, we have the opportunity to use them to replace nuclear warheads or at least using them with lower yield, less indiscriminate nuclear warheads.

For most of us, the risk of nuclear war is currently far too real, but if we succeed in avoiding nuclear conflict for a few more decades, we could find nuclear weapons playing a much less dominant role in strategic plans. In the meantime, even if we were willing to abandon our nuclear arsenals, we cannot count on other nations to voluntarily give them up as long as these arsenals provide the most effective force for implementing policy and achieving military objectives. But, as the applications of high technology become more effective, we will not need treaties or entreaties to ban or abandon nuclear warheads.

Within a few decades, our understanding of the world's atmosphere, weather, and climatology will have advanced so much that we will be more certain of the worldwide effects of fallout, dust, smoke, and other extended effects from nuclear war. We will be able to predict the global consequences with greater reliability. Without experiencing nuclear warfare, however, we may never be sure that we have identified and adequately quantified all of the destructive aspects of nuclear conflict. The risk of consequences unforeseen, on a scale never before imagined, is a price we must accept for being fortunate enough to have avoided nuclear warfare for nearly forty years.

I foresee relief for the world from the threat of widespread nuclear devastation in the long-term. Our principal problem, I believe, is how to ensure that we last long enough to get that relief.

In the near-term, we are still contending with large and growing arsenals of nuclear-tipped weapons. A global or hemispheric chill, with unseasonable freezing weather, which might follow a nuclear holocaust, poses a serious additional, undesirable consequence. But predictions of this threat contain many elements of uncertainty.

It is hardly necessary to acknowledge that strategic policy should take into account all of the important aspects of nuclear weapon employment, including the possible global consequences. It may be viewed as thoughtless as well as heartless to argue that the direct nuclear war damage due to blast, fire, and radiation would be so overwhelming as to dwarf the possible consequences of an unseasonable cold spell in the aftermath of a major nuclear exchange. At the same time, to suggest that failed crops and cold weather are disasters on a par with the unprecedented death and destruction that would result from nuclear war, bespeaks an inability to comprehend the enormity of the immediate damage from such a war.

It would pose a difficult and sensitive task to restructure or reassign the bulk of the U.S. and Soviet nuclear forces so as to minimize or avoid the suggested global consequences of their unrestrained employment. A drastic departure from current deployments might be called for, which would not be lightly undertaken. Nor would it be easily justified, considering the uncertain basis for present predictions of these global consequences. It is equally unlikely that we could convince foreign nations to abandon their force structures on the strength of the current uncertain projections.

It is in recognition of these plaguing uncertainties that most groups and individuals who have chosen to comment on the subject of global effects have supported a continued or enlarged research effort.

Experiments on a global scale are nearly inconceivable, but many aspects of the smoke and dust problem can be studied through calculation and laboratory experimentation. The materials liable to burn in cities and rural or wildland areas can be surveyed. Their likely burn dynamics can be studied more carefully, and expected burn rates, smoke output, and the particle sizes in the ash and soot and total amounts lofted into the atmosphere can be more carefully catalogued. The agglomeration of smoke particles and the processes of scavenging, (the process of removing smoke particles by mixing, precipitation, and chemical reaction) are being studied for their relevance to this global "smoke screen". The dispersion rates of smoke clouds and the altitudes to which smoke is carried in fire plumes are also being examined. New and more sophisticated models of global atmospheric circulation are being constructed so that we can probe the ultimate destructive consequences of the unprecedented smoke loads that might result from nuclear war.

Not all of this research will be rewarded immediately with conclusive results. Many of the important factors will remain uncertain and their possible impact will remain the subject of controversy. I do not foresee any quick solutions or easy answers for the strategic policy advisers on this issue. In the light of persistent, uncertain consequences of global proportions, what are our options or alternatives? I can readily list a few.

1. We could do nothing. Counting on deterrence to continue to work, perhaps the least disruptive, least costly action is no action. In time, with clearer understanding, changes in force structure and policy could be made. The risk remains that if a war occurred in which nuclear weapons were unrestrictedly employed, we would be facing the possibility of the worst cold spell in 10,000 years.

It may be argued that the global consequences are so serious as to preclude inaction. But here the dilemma is that the direct death and destruction are surely as serious. Our strategic deterrence is not only a vital issue for the nation (and much of the rest of the world) but it represents an enormous capital investment in the machines of war and supporting facilities, as well as vast manpower resources and commitments. As with a huge corporation, changes in major products or processes cannot be accomplished without immense efforts, thorough planning, and justification. Responsible national leaders may prefer to delay altering the force structure until full justification and adequate examination of the ramifications for change have been provided. They may view a crash program to implement added constraints as imprudent, even when the new perceptions include the possibility of greater misery and suffering if they do not act now, and war should occur.

2. We could limit our strategic options or select weapons such as to avoid their use on cities, assuming that burning cities would contribute the most serious smoke load. Attacking cities while our forces (or those of others) are still largely intact may be poor tactics, anyway. Leaving an enemy's cities unburned makes them hostages, and may induce the enemy to avoid our cities, as well.

Recent detailed estimates suggest that a serious global chill due to smoke from fires would not be probable from nuclear attacks on nearly all strategic targets outside urban areas. These estimates of smaller wildland and rural fire contributions to the smoke burden from a counterforce (city-avoidance) attack are still subject to further study and discussion. But so far, they illustrate the large uncertainties involved and the importance of reducing them.

While there is some basis for seriously considering city-avoidance scenarios, there is also reason to doubt their credibility. Concentrating weapons on empty silos in response to an enemy missile barrage may prevent or inhibit reloading of those silos for second or subsequent attacks, but that fact hardly justifies the expenditure of our surviving strategic forces in that fashion. In addition, it may not represent much deterrence value once the exchange has occurred.

Planning city-avoidance options brings into question the objectives of a strategic deterrence force. If we are unable or unwilling to attack enemy targets within urban areas, then many of his leadership, key industry and military targets within those cities are at less risk. Our forces would appear less as a deterrent and more as a temptation.

Nevertheless, if we refrain from burning enemy cities, we may reduce the atmospheric smoke load, and so reduce the global consequences as well as spare the lives of many millions of urbanites. That may be small consolation to us or the rest of the world if such restraint is not shared. If our cities, as well as much of our countryside, are burned, the additional smoke load might still lead to subsequent unseasonably cold weather around the globe.

3. We could limit the weapon yields employed to well below a megaton. Lower yield weapons would cause smaller fires and generate lower altitude nuclear clouds and smoke plumes. Smoke at low altitude will come down out of the atmosphere more rapidly than smoke injected into the stratosphere. However, the value of using only low yield weapons is dubious, since smoke and nuclear clouds can still reach the stratosphere with the aid of condensation in a moist atmosphere or due to subsequent solar heating. However, the employment of lower yields, causing smaller fires and lower smoke plumes, would be a step in the direction of reducing the global effects of dust, smoke, and fallout. But if more low yield weapons are used to replace large yield weapons, the areas at risk may not be much reduced. It is not clear that we have any leverage by which to persuade the Soviets (who already deploy larger yields than the U.S.) to correspondingly reduce their warhead yields.

4. We could plan alternative weapon employments for the summer months--in summer, wildland fires contribute more smoke and there is greater potential for crop devastation. Such a compromise could avoid the worst possible global situation. Planning for such seasonal flexibility would place great burdens on the management of strategic forces, however, and would surely be resisted unless we could produce

solid evidence of its necessity. Again, our own efforts might have little consequence without Soviet cooperation. If we could arrange such cooperation, why not press on for more comprehensive arms reductions?

5. We could institute weapon changes that would help minimize fires and high-altitude dust clouds. Weapons that penetrate the ground before detonation might reduce the range for fires, and still cause intense damage in the target area. Earth-penetrating weapons would also deposit more of their radioactive fallout locally, and so, in many cases, reduce the worldwide radiation hazard. Shallow-buried weapons are not appropriate for all targets, but they may be even more effective than airburst or surface-burst weapons against hard targets such as missile silos and buried bunkers. With smaller fire areas and lower smoke clouds, the dust and smoke plumes would not last as long or go as far.

6. We could continue to provide selective options to ensure flexibility in application, so that decisions including global consequences are not precluded. The judgment about the real dangers from global effects and how carefully we wish to avoid them, is then left until the time of option selection. In times of crisis, decision-making is often based on principles or priorities starkly different from times of normalcy, and while we run the risk of ignoring the global consequences in the rush to battle, it would allow national commanders the fullest flexibility. It would also avoid unnecessarily restricting their options under the dire and somewhat unforeseeable circumstances of imminent nuclear war.

7. Although none of the previously mentioned options result in the immediate elimination of nuclear warfare as a possible instrument of national policy, we could abandon all strategic use of nuclear weapons. Since we are not in a position to guarantee that the rest of the world would follow our example, it would be quite imprudent for us to forsake nuclear weapons unilaterally. Yet, reducing the capacity of world powers to employ nuclear weapons is such an attractive path toward a less violent world (and one which would lead to a world less

likely to suffer unprecedented damage and loss of life), that we ought to avail ourselves of every reasonable opportunity to limit their availability or utility around the world.

Our nation is embarked now on such a mission. The goal is to find ways to reduce the nuclear capabilities of both the Soviets and the U.S., without raising the risk of conflict or unbalancing the deterrent effects of one upon the other.

Indisputably, research can help clear up some of the controversy and reduce more of the uncertainties surrounding the estimates of global effects. Unlike some applied research for military purposes, much of the work on the issue of global smoke and dust from nuclear war can be beneficially applied to such worthy investigations as climatology, vulcanology, weather research, upper atmospheric physics, and fire research. In view of the importance of the subject and the potential for successful contribution, the current research program is quite modest. There is good reason to believe, however, that it will ultimately place this aspect of nuclear warfare in better perspective.

Mr. UDALL. All right, thank you.

Let's bring our other two panelists over at this end of the table now, Mr. Schneider—Dr. Schneider and Mr. Carrier—Dr. Carrier.

Dr. Carrier, you may give us about 5 minutes of what we ought to know at the end of the day here.

STATEMENTS OF DR. GEORGE F. CARRIER, HARVARD UNIVERSITY, CAMBRIDGE, MA, AND CHAIRMAN OF THE COMMITTEE ON ATMOSPHERIC EFFECTS OF NUCLEAR EXPLOSIONS, NATIONAL ACADEMY OF SCIENCES, WASHINGTON, DC; AND DR. STEPHEN H. SCHNEIDER, DEPUTY DIRECTOR FOR ADVANCED STUDY PROGRAMS, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH, BOULDER, CO

Dr. CARRIER. Yes; I'm here, as you probably know, because I chaired the committee of the National Academy of Sciences which conducted a study on this nuclear winter thing. You will see that my remarks are in some way a summary of fragments of previous comments by other witnesses coming as late in the day as it does.

As you know, the weapons have as relatively direct effects the manufacturing of nitric oxide, dust and smoke, and those things are lofted high in the atmosphere. They interact with the incoming solar radiation and they lead to a degradation of the atmosphere. It's clear that those things happen.

The great uncertainty has to do with the intensity and the duration of such things. Some of the uncertainties will always be there. You'll not know before a given event at what season it might occur, what weapons might be used, what targets they will actually reach, and things of that sort. So that there are some uncertainties that we're not going to resolve no matter what we do.

On the other hand, the very great uncertainties indeed in the amount of smoke and the altitude to which it gets and the rate at which it gets removed can be narrowed. And one could come closer to a definitive statement as to what the degradation of the atmosphere would really be if those questions were resolved to the extent that they can be in a sensible manner.

There is also, however, a degree of uncertainty in our ability to predict the response of the atmosphere to even precisely given amounts of contaminant material in the atmosphere. And since we will not conduct any prototype experiments to test such things, it's clear that some of that uncertainty will also remain.

The fact is that the committee felt strongly that research to narrow those things which could be narrowed was in order. We recommended such research. As nearly as I can tell by reading the DOD manuscript which has been referred to earlier this morning, the program they have put in place is consistent with what we recommended. Whether there are gaps in it, I can't tell from that reading.

I guess I would like to remind you of one thing, though. Whenever one undertakes an enterprise that is as complicated a composite of individual research tasks as this one is, and in which each of them is as intricate as it is, and is fraught with statistical kinds of things, it is bound to be true that, during the course of the investigation, questions are going to arise that were not anticipated at the beginning of the program. And I would hope that the manner in which this program is coordinated and managed in general would have the flexibility so that, as questions arise that were not anticipated, they can be subsumed into the process so that we don't continue to have the holes that we have no way of knowing are there today. It has to be flexibly managed, and I hope that's realized by those who are supporting such things.

[The prepared statement of Dr. Carrier follows:]

NATIONAL RESEARCH COUNCIL
COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES
2101 Constitution Avenue Washington, D.C. 20418

Joint Hearings

by the

Subcommittee on Natural Resources,
Agriculture Research and Environment
Committee on Science and Technology

and the

Subcommittee on Energy and Environment
Committee on Interior and Insular Affairs
U.S. House of Representatives

Testimony by

Dr. George F. Carrier

T. Jefferson Coolidge Professor of Applied
Mathematics, Harvard University

and

Chairman, Committee on the Atmospheric
Effects of Nuclear Explosions, National Research Council

Dr. Carrier will refer to the National Research Council report,

The Effects on the Atmosphere of a Major Nuclear Exchange,

Executive Summary attached.

March 14, 1985

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering to serve government and other organizations

The Effects on the Atmosphere of a Major Nuclear Exchange

Committee on the Atmospheric Effects
of Nuclear Explosions

Commission on Physical Sciences, Mathematics,
and Resources

National Research Council

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Washington, D.C. 1985

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1

Summary and Conclusions

The Committee on the Atmospheric Effects of Nuclear Explosions addressed the following charge: (1) determine the manner in which the atmosphere of the earth would be modified by a major exchange of nuclear weapons and, insofar as the current state of knowledge and understanding permits, give a quantitative description of the more important of the changes, and (2) recommend research and exploratory work appropriate to a better understanding of the question.

The committee was not asked to (and did not) address the related but distinct questions of the extent of radioactive fallout or the biological or social implications of postwar atmospheric modification.

Recent calculations by different investigators suggest that the climatic effects from a major nuclear exchange could be large in scale. Although there are enormous uncertainties involved in the calculations, the committee believes that long-term climatic effects with severe implications for the biosphere could occur, and these effects should be included in any analysis of the consequences of nuclear war. However, the committee cannot subscribe with confidence to any specific quantitative conclusions drawn from calculations based on current scientific knowledge. The estimates are necessarily rough and can only be used as a general indication of the seriousness of what might occur.

Despite the early state of understanding of these matters, the possibility of severe degradation of the atmosphere after a major nuclear exchange is of sufficient national and international concern that a major effort to narrow the scientific uncertainties should be given a high priority.

BACKGROUND

It is widely understood that any major nuclear exchange would be accompanied by an enormous number of immediate fatalities; nevertheless, a much larger fraction of the human population would survive the immediate effects of a nuclear exchange. This study addresses current knowledge about the nature of the physical environment the survivors would have to face.

The realization that a nuclear exchange would be accompanied by the deposition into the atmosphere of large amounts of particulate matter is not new. However, the suggestion that the associated attenuation of sunlight might be so extensive as to cause severe drops in surface air temperatures and other major climatic effects in areas that are far removed from target zones is of rather recent origin. That perception has grown out of a number of recent investigations. Crutzen and Birks (1982) recognized that the amount of smoke from the fires ignited by nuclear blasts could be of crucial importance, and Alvarez et al. (1980) hypothesized that the massive species extinctions of 65 million years ago were part of the aftermath of the lofting of massive quantities of particulates resulting from the collision of a large meteor with the earth. Others have recognized the similarity between the Alvarez dust hypothesis and the effects of nuclear war (see Appendix).

The consequences of any such changes in atmospheric state would have to be added to the already sobering list of relatively well-understood consequences of nuclear war, including prompt radiation, blast, and thermal effects, short-term regional radioactive fallout, inadequate medical attention for surviving casualties, and the long-term biological effects of global fallout. Long-term atmospheric consequences imply additional problems that are not easily mitigated by prior preparedness and that are not in harmony with any notion of rapid postwar restoration of social structure. They also create an entirely new threat to populations far removed from target areas, and suggest the possibility of additional major risks for any nation that itself initiates use of nuclear weapons, even if nuclear retaliation should somehow be limited.

THE COMMITTEE'S BASELINE CASE

To provide a framework for its study, the committee first constructed a baseline war scenario, made up of assumptions concerning the nature of the weapon exchange. The baseline scenario (see Chapter 3 for greater detail) was selected so as to be representative of a general nuclear war: one-half--about 6500 megatons (Mt)--of the estimated total world arsenal would be detonated. Of this, 1500 Mt would be detonated at ground level. Of the other 5000 Mt that would be detonated at altitudes chosen so as to maximize blast damage to structures, 1500 Mt would be directed at military, economic, and political targets that coincidentally lie in or near about 1000 of the largest urban areas. All explosions would occur between 30°N and 70°N latitude.

The committee also chose, on the basis of a review of the scientific literature, a set of baseline physical parameters to use in calculating the effects of the baseline weapon exchange. Each baseline parameter was chosen to lie well within the spectrum of scientifically plausible values, values in the middle ranges of plausibility being preferred.

There are three immediate consequences of a major nuclear exchange that could have a significant impact on the subsequent state of the atmosphere. Large amounts of dust could be lofted high into the atmosphere; large fires could be initiated; and large amounts of undesirable chemical species could be released. Some of the key parameters assumed for the baseline case follow.

The amount of dust (Chapter 4) that would be deposited in the stratosphere is related to total megatonnage. The committee assumes that the total amount lofted is 0.3 teragrams (1 Tg = 10^{12} g = 10^6 metric tons) per megaton detonated. Eight percent of the mass of dust would be of submicron size, which remains aloft for long periods. The 1500 Mt in ground bursts would raise about 15 Tg of submicron dust into the stratosphere, where it could reside for more than a year. During that time, the solar radiation through that dust, and into the lower atmosphere, would be reduced.

The analysis of fires and smoke is complex (Chapter 5). The 5000 Mt of air bursts would initiate vigorous fires in cities and forests over areas where the thermal radiation incident on combustible material was 20 calories per square centimeter (cal/cm^2) or greater, a number well in excess of that known to be adequate to ignite the fuels at hand. In the city-scale urban conflagrations that would ensue, the baseline assumption is that three-quarters of the combustible material in affected areas would be consumed. (Nearly complete consumption of combustible materials is typical of large city-wide fires for which data are available.) Although many of the urban fires would probably spread beyond the 20 cal/cm^2 ignition zone, no additional fuel burden from that spreading is assumed in the baseline case. Of the material that burned in cities, the baseline case assumes that some 4 percent (limited data suggest values lying between 1 percent and 6 percent) would be converted to smoke particles in a range of submicron sizes that would absorb and scatter sunlight very effectively.

Certain processes may, however, diminish the optical effects of the smoke at this stage. During the burning of the urban and/or forest fires, the very fine smoke particles would undergo some coagulation in the rising plume. Over regions where the ambient ground-level humidity was high, the condensation of moisture entrained in the plume could incorporate some of the smoke. There is little empirical evidence to suggest extensive scavenging of the smoke by these processes, but in the baseline case, 50 percent of the smoke is assumed to be removed from the plumes of urban fires in this manner.

On the basis of available information on plume dynamics, it is assumed that, shortly after deposition the smoke from the ensemble of fires would be uniformly distributed vertically (mass per unit height) between 0 and 9 km over the entire affected area; the local vertical distribution would be nonuniform, however, because the altitudes of the smoke plumes would vary from one fire to another and would also vary with the time-dependent intensity of the fire. Although under special meteorological circumstances some of the smoke might be deposited at altitudes significantly higher than 9 km, this effect is ignored in the baseline case. Initially, and for some weeks, the smoke would have a very nonuniform horizontal distribution, but would be distributed throughout the troposphere of the northern temperate zone.

The injection of nitrogen oxides from the nuclear clouds into the upper atmosphere would lead to a depletion of the ozone column, which would be restored in about 2 years (Chapter 6).

The atmospheric implications of the baseline case (and of the results of other groups' analyses) are presented in Chapter 7. The committee expects that solar radiation passing through the stratospheric layer of nuclear dust would be absorbed in the upper regions of the smoke layer. The smoke layer would heat up, and since little solar radiation would reach lower levels, the air over land surfaces would cool.

Although a few types of natural events can provide marginally relevant information on aspects of the problem (see also Chapter 8), much of our understanding of the atmospheric response to large amounts of airborne particulates will come from model simulations. These models are validated within relatively small natural variations, so their predictive capability is limited for these large perturbations. Only preliminary estimates can be made of the rate of spreading of particulates over initially clear latitudes and of the rate of removal of particulates.

The duration and magnitude of atmospheric effects would depend on how long the absorbing particulates remained aloft. There is especially large uncertainty associated with long-term removal processes for smoke that survives the early scavenging. Low-altitude precipitation processes might remove the low-altitude smoke, that below 4 km (the normal range for smoke), rather efficiently. But at high altitudes, the increased air temperature and the low humidity could lead to a removal rate in the 4- to 9-km range that would be slower than the removal rate in today's troposphere. The baseline assumes that removal rates would be at least comparable to normal removal rates in the lower atmosphere (below 5 km), but would be slightly slower than normal in the upper troposphere (5 to 10 km), with about one-half of the initial particulates removed from the lower atmosphere in 3 days, and from the upper atmosphere in 30 days.* It is unlikely that the average residence times for postwar smoke would be much less than these values, and quite possible that the mean residence time in the upper troposphere would be longer.

It is hoped that the committee's baseline case will provide a useful point of departure for those who wish to identify and assess the environment that would prevail following a major nuclear exchange.

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*If the smoke particles acquired electrical charges, the coagulation and smoke removal times could be affected. However, there is no evidence from large historical fires that electrical activity intense enough to be observed was operative. Furthermore, there is no evidence that the sometimes large and visible electrical effects in intense natural events (e.g., tornadoes and volcanoes) influence the dynamics of the storm. Thus, having no reliable basis on which to do otherwise, the committee has disregarded potential electrical effects.

NOTES ON THE NATURE AND SIGNIFICANCE OF UNCERTAINTY

As may be clear from this brief description of the baseline case, there are many points in the analysis at which there is a wide range of parameter values that are consistent with the best current scientific knowledge. Any estimate of the overall atmospheric response will involve a compounding of the effects of these uncertainties. Obviously, calculations made under these conditions cannot be read as a scientific prediction of the effects of a nuclear exchange; rather, they represent an interim estimate from which the reader can infer something of the potential seriousness of the atmospheric degradation that might occur.

Some reviewers of earlier drafts of this report cautioned that even the most qualified numerical results produced under these conditions could be misinterpreted, and some suggested that at present the only scientifically valid conclusion would be that it is not at this time possible to calculate the atmospheric effects of nuclear war. The committee believes, however, that an appropriately qualified, preliminary quantitative treatment of the problem is warranted on two grounds. First, given the enormous human stakes that may be involved, it may not be advisable to wait until a strong scientific case has been assembled before presenting tentative results; there is a danger that a report that reached no conclusions at all would be misconstrued to be a refutation of the scientific basis for the suggestion that severe atmospheric effects are possible. Second, a quantitative approach to the problem is the best way to ensure that all important factors are systematically considered, and quantification helps distinguish the important factors from the less important ones in the overall analysis. Such results are necessary to the orderly allocation of resources to the most pertinent research questions.

The findings of this report depend in rather large measure on a still limited body of scientific inquiry, some of which is not yet fully documented. Attention to the subject is so recent, in fact, that some of the underlying analysis has not yet undergone the peer review process that precedes publication in most scientific journals.

The reader should appreciate the possibility that further research may well invalidate some of the estimates discussed in this report. As recently as 1975, when the National Research Council report Long-Term Worldwide Effects of Multiple Nuclear Weapons Detonations appeared, plausible weapon use scenarios differed significantly from those envisaged today, and the crucial importance of fires and smoke had not then been recognized. It follows that the findings presented in this report differ from those of the 1975 report. Furthermore, the pervasive uncertainties in the data and the limited validity of the atmospheric models used to date imply that some future study, conducted at a time when the data and models have been improved, could produce quite different analyses and conclusions. It is possible that improved understanding of some mechanisms (e.g., early scavenging) could so affect the results that the atmospheric degradation would be shown to be weaker than that estimated in the baseline case, but the same uncertainty also makes it a clear possibility that the exchange could produce a degradation that would be greater than, and would last longer than, that estimated in the baseline case.

In short: the committee's findings are clearly and emphatically of an interim character.

A vigorous research effort is now needed. Nevertheless, one cannot expect that long-term nuclear effects will be characterized with great precision or confidence in the next few years. Many uncertainties cannot be narrowed because they depend on human decisions that can be made, or changed, long after any particular prediction has been issued. These include, for example, the total yield of the exchange, individual warhead yields, the mix of targets, the mix of altitudes at which the bursts would occur, and the season of the year in which the exchange would occur. In addition, there are obvious limits to the use of large-scale experiments in this field, and the evolution of atmospheric models will require some time.

Many significant uncertainties, however, can be narrowed by further study. In particular, the heights to which smoke is deposited in city-scale fires, the early smoke removal by coagulation and condensation in the fire plume, the extent of continued buoyant rising of sun-heated opaque clouds, and the dynamical response of the atmosphere, first to patchy high-altitude solar absorption and then to the heating of more broadly distributed but still heavy smoke cover, have received only scattered and recent attention.

CONCLUSIONS

The general conclusion that the committee draws from this study is the following: a major nuclear exchange would insert significant amounts of smoke, fine dust, and undesirable chemical species into the atmosphere. These depositions could result in dramatic perturbations of the atmosphere lasting over a period of at least a few weeks. Estimation of the amounts, the vertical distributions, and the subsequent fates of these materials involves large uncertainties. Furthermore, accurate detailed accounts of the response of the atmosphere, the redistribution and removal of the depositions, and the duration of a greatly degraded environment lie beyond the present state of knowledge.

Nevertheless, the committee finds that, unless one or more of the effects lie near the less severe end of their uncertainty ranges, or unless some mitigating effect has been overlooked, there is a clear possibility that great portions of the land areas of the northern temperate zone (and, perhaps, a larger segment of the planet) could be severely affected. Possible impacts include major temperature reductions (particularly for an exchange that occurs in the summer) lasting for weeks, with subnormal temperatures persisting for months. The impact of these temperature reductions and associated meteorological changes on the surviving population, and on the biosphere that supports the survivors, could be severe, and deserves careful independent study.

A more definitive statement can be made only when many of the uncertainties have been narrowed, when the smaller scale phenomena are better understood, and when atmospheric response models have been constructed and have acquired credibility for the parameter ranges of this phenomenology.

The committee also draws several more specific conclusions:

1. In an extensive nuclear exchange, explosions over urban areas and forests would ignite many large fires. Massive smoke emissions are an important aspect of nuclear warfare that have only recently been recognized. For the major 6500-Mt nuclear war considered here, fires could release massive amounts of smoke into the troposphere over a period of a few days. Much of the smoke might be removed by meteorological processes within several weeks, depending on feedback effects, but significant amounts could remain for several months. During its tenure in the atmosphere, the smoke would gradually spread and become more uniformly distributed over much of the northern hemisphere, although some patchiness would be likely to persist. Light levels could be reduced by a factor of 100 in regions that were covered with the initial hemispheric average smoke load, causing intense cooling beneath the particulate layer and unusually intense heating of the upper layer. While large uncertainties currently attend the estimates of smoke emissions, and of their optical and physical consequences, the baseline case implies severe atmospheric consequences.

2. The production of smoke from fires, and the implied effects on the atmosphere, is more directly linked to the extent of detonation over urban areas than to the aggregate yield of a nuclear exchange. The industrialized nations of the world have concentrated a large proportion of their resources and combustible fuels in the vicinity of the central areas of their large cities. Any war scenario that subjects these city centers to nuclear attack, even one employing a very small fraction of the existing nuclear arsenal, could generate nearly as much smoke as in the 6500-Mt baseline war scenario.

3. The climatic impact of soot is very sensitive to its lifetime in the perturbed atmosphere and the uniformity of its distribution. The lifetime of soot is highly uncertain, particularly in the upper troposphere. The perturbation itself would produce severe new effects, many of which could tend to increase the residence time of the soot. Although the lofted soot (and dust) would rapidly spread around the latitude band of injection, the distribution could be uneven for several months, with continent-size patches of lesser and greater density, particularly near the southern edge of the affected zones.

4. In the baseline nuclear war scenario, hundreds of teragrams of dust would be injected into the atmosphere from surface detonations. A significant fraction of the dust consisting of particles with radii less than one micron (1 μm) would be expected to remain aloft for months. About one-half of these submicron particles would be injected into the stratosphere and would produce some long-term reduction of sunlight at the earth's surface, even after smoke and dust at lower altitudes were removed. This stratospheric dust alone would lead to

perceptible reductions in average light intensities, and continental surface temperatures would fall measurably. In a plausible scenario that involves more ground burst attacks against very hard targets than are assumed in the baseline case, the possible dust effects are several times larger.

5. It is not possible at this time to estimate the most probable average temperature changes at the surface caused by smoke and dust lofted in the baseline case; nor would such a single value, even if available, meaningfully describe the situation. In addition to the large uncertainties in many of the critical physical parameters and the inherent limitations of the models available for computer simulations, the available calculations reflect wide seasonal and geographical differences. Recent general circulation model simulations that incorporate simplifying assumptions indicate that a baseline attack during the summer might decrease mean continental temperatures in the northern temperate zone by as much as 10° to 25°C, with temperatures along the coasts of the continents decreasing by much smaller amounts. In contrast, an attack of the same size during the winter, according to these simulations, might produce little change in temperature in the northern temperate zone, although there could be a significant drop in temperatures at more southern latitudes.

6. The nitrogen oxides deposited in the stratosphere by nuclear detonations would reduce the abundance of ozone. For the 6500-Mt nuclear war, the northern hemisphere ozone reduction could become substantial several months after the war. Estimates based on current stratospheric structure suggest that the amount of ozone reduction would decrease by one-half after about 2 years. At the time of maximum ozone reduction, the biologically effective ultraviolet intensity (using the DNA action spectrum) at the ground would be approximately one and one-half times the normal levels. Initially, the presence of dust and smoke particles in the atmosphere would provide a measure of protection at the surface from the enhanced ultraviolet radiation. This protection would gradually diminish as the particles were removed.

7. This study has concentrated on the possible effects that a nuclear war could have on the northern hemisphere, primarily within the mid-latitude region (30°N to 70°N) where the nuclear exchange would be concentrated. It is particularly difficult to assess the potential effects of the baseline war on the atmosphere of the northern tropics and southern hemisphere. Although southern hemisphere effects would be much less extensive, significant amounts of dust and smoke could drift to and across the equator as early as a few weeks after a nuclear exchange. A large rate of transport across the equator driven by heating in the debris cloud cannot be ruled out. Indeed, such heating-enhanced cross-equatorial circulation has been found for spring and summer months in computer simulations.

8. Some prehistoric volcanic eruptions and impacts from extraterrestrial bodies have released energies corresponding to levels that would be released in a major nuclear exchange and may have lofted massive amounts of dust; however, neither type of event provides a useful direct analog to the nuclear case because neither type involved the production of highly absorbing soot particles. Furthermore, the

atmospheric consequences of prehistoric natural events of these proportions are not known, and their effects on the fossil record, if any, have not been sought in any systematic way. Accordingly, available knowledge about prehistoric volcanic and impact events provides neither support nor refutation of the committee's conclusions.

9. All calculations of the atmospheric effects of a major nuclear war require quantitative assumptions about uncertain physical parameters. In many areas, wide ranges of values are scientifically credible, and the overall results depend materially on the values chosen. Some of these uncertainties may be reduced by further empirical or theoretical research, but others will be difficult to reduce. The larger uncertainties include the following: (a) the quantity and absorption properties of the smoke produced in very large fires; (b) the initial distribution in altitude of smoke produced in large fires; (c) the mechanisms and rate of early scavenging of smoke from fire plumes, and aging of the smoke in the first few days; (d) the induced rate of vertical and horizontal transport of smoke and dust in the upper troposphere and stratosphere; (e) the resulting perturbations in atmospheric processes such as cloud formation, precipitation, storminess, and wind patterns; and (f) the adequacy of current and projected atmospheric response models to reliably predict changes that are caused by a massive, high-altitude, and irregularly distributed injection of particulate matter. The atmospheric effects of a nuclear exchange depend on all of the foregoing physical processes ((a) through (e)), and their ultimate calculation is further subject to the uncertainties inherent in (f).

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Mr. **Udall**. Thank you.

Dr. Schneider.

Dr. **Schneider**. Thank you very much.

As the last formal witness, I have the self-imposed role of being the junkman. I'll try to bring up those points which I feel may have been missed in the discussion, even though they may not adequately reflect the balance of my overall views. I have submitted for the record, and I have more copies here, a formal testimony. And since much of what I otherwise would have said has been covered, I'll try to go over points which either have been missed or I feel inadequate, and then be subject to questions later.

The first thing that I've been concerned about is—and this does relate to the Department of Defense's report—was something that may have been missed, at least it was missed to the strength I would have liked to see it. If one reads through the discussion of the so-called nuclear winter problem, you clearly came away with a sense that, yes, there's a real potential and, yes, there are a great deal of uncertainties. But what was not phrased in the way that would be to my satisfaction was that what you're really looking at is a problem which has to be viewed probabilistically. Uncertainty is not the same thing as no effect, of course. And the way I prefer to view it, probabilistically, is that there is a higher probability of lower consequences and a lower probability of higher consequences.

To translate that, there's a likelihood that even very much limited wars, well below the levels that have been talked about by the TTAPS group or even the National Academy of Science baseline, whereby plumes of drifting smoke could randomly move around the hemisphere selecting almost by a weather roulette places where temperatures could drop below freezing or near freezing for periods of days, not the global scale nuclear winter that we're talking about. But that, should it be in the summer half year or growing season, or in the subtropics at any season, could be of tremendous devastation to those people who experience that, as the Florida citrus industry does whenever there's—transient freeze outbreaks occur. This, to me, would be a fairly high probability on the scale of what we're looking at, even at limited or theater scale wars.

And the lower probability event would be the global scale full freeze of the kind that so scared the biologists who studied it and suggested the possibility even of extinction of human beings, a possibility which although I would consider remote, as they said, can't be ruled out. The point is the only way to achieve that would be if there were a full exchange. In fact, if we had a perfectly designed computer launch on warning system where, in fact, we were able to get everything off if somebody else launched first, then we might be able to approach the levels of smoke where that would be possible.

But when you view this as a sliding scale of probability, then you realize that all plans that include more than full-scale exchanges—and everything I have heard from my limited contacts and readings is that nobody rational believes in full-scale exchanges—but there are people who believe in their own rationality and believe in limited exchanges, but even limited exchanges are not necessarily exempt from transient events that could occur.

This may have major impact on what we've called the "first strike feedback" scenario. An example of it is in my testimony, from my colleagues, and from the Los Alamos group and the Livermore group and the Soviet group, and we have all run these examples. And one that we just ran put smoke, about half the amount that the Academy assumed in its baseline, over both the U.S.S.R. or the Soviet Union independently and, indeed, it is a situation where those smoke plumes not only caused transient cooling effects over the struck country, but drift back around onto the territory of the continent of the others. And depending on the season and other specific details which are not able to be answered now, and probably ever, could have effects elsewhere as well.

The noncombatants are, therefore, significantly affected by this. And I haven't heard it mentioned before here that noncombatants also are involved, both as our friends and our adversary's friends, and—in fact, a friend of mine in Canada refers to this as the "ICBM problem into Canada by mistake." And there are many nations which may be involved in the nonproliferation treaty discussion that's coming up for which they may call the United States and the U.S.S.R. to task for their possible impact on their territories from any nuclear exchanges, and they may have something to say, which I didn't see discussed in that report or I haven't heard discussed before.

I'm sure that my colleague, George Rathjens, who I was going to chide for commenting on what temperatures were possible—George coming from a now largely political science background, will chide me for making comments on policy. But I felt that that issue should at least be considered.

Another area which has not been, in my opinion, adequately explored: in the DOD report I read a short paragraph in there from FEMA about civil defense. And regardless of one's views about whether civil defense is effective or not, it certainly struck me as a strange statement to say that because there was so much scientific uncertainty surrounding nuclear winter, therefore, FEMA couldn't make any plans. I always believed that strategic planning was based upon anticipating a whole host of events whose probabilities could be an order of magnitude or more below that for nuclear winter, and that it would be certainly legitimate activity for us to ask, 'So what if?" That, in fact, is the purpose I always thought of for strategic planning. And obviously whether or not they should make any modification, I don't know, but clearly one shouldn't use the argument that there's technical uncertainty and, therefore, we have nothing to say in the policy area. I believe that's true for almost every aspect of this problem.

Secretary Perle said that with regard to biological consequences—the question from Congresswoman Schneider—no relation—that misses the point. Actually, in a sense, I have a philosophical disagreement with the Secretary there, as I did, Congressman Scheuer, when I testified before this committee 4 years ago over a different issue, over the greenhouse effect question, the CO^2 problem, with the Department of Energy, who were deemphasizing the social and biological consequences of CO^2, arguing that we had many uncertainties in physical science. Not that I disagree with the fact that there are uncertainties in the physical science, but the question of "so what" if the event the physicists are looking at occurs, should in fact not follow, but precede, the physical science investigation.

And it has a scientific component, because the variables that we look at and try to study can be influenced by what impact assessments tell us. We want to find out is it 3 meters of ice over the winter that counts and, as Dr. Sagan has said and Richard Perle has agreed, this is terrible and we all agree, but what about a flickering temperature decrease? Biologists tell us in some seasons that's almost as severe.

And finally, also Secretary Perle commented that there might be a nonutility, if you will, from the U.S.-U.S.S.R. scientific exchange based on the fact that the Soviet scientists have official positions. In my experience in that regard, he's not incorrect that it's hard to shake them from the position they come with. On the other hand, if we really want the Soviet scientists to understand the range of uncertainty associated with nuclear winter and what it means, it's very difficult to do that from the literature alone. There really aren't 50 scientists in the world, in my personal opinion, who are capable of evaluating all these details. No individual one is. And that's 50 collectively. And we have to meet together to do that. And even if they're not going to admit it, they'll learn how to read the literature better if we are able to meet with them face to face and they bring that kind of information home.

Finally, the bottom—and again, this is a personal observation—line to me of nuclear winter is not that we have a detailed set of certainties about what will happen. In fact, I'm personally glad that we may never be able to have a specific scenario where in a given day the winds are such, the humidity is such, and the following season we'll know what's going to happen. Because if we were able to do that, then nuclear winter or some weather effect could be factored in as a military strategy. And indeed, one can concoct—and we do this on individual days on our models—scenarios whereby we or they end up better off or worse off, thereby increasing rather than decreasing the probability of exchanges. Fortunately, the technical uncertainties conspire to prevent us from having any confidence in any such detailed scenario and force us into talking in broad sweeps like it is reasonably probable that flickering quick freezes or large-scale events could occur. And while I have no doubt that research now on those uncertainties will put decisionmaking on a firmer basis, I don't think we'll ever be in the position where that level of detailed scenario will be easily possible and, from a personal point of view, I'm glad of it.

Thank you.

[The prepared statement of Dr. Schneider follows:]

Testimony of

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on

Nuclear Winter:
State of Science and Observations on Its Implications

before

House of Representatives

Subcommittee on Natural Resources, Agricultural Research and Environment

of the

Committee on Science and Technology

and the

Subcommittee on Energy and Environment

of the

Committee on Interior and Insular Affairs

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No recent atmospheric scientific topic has been more talked about, controversial, and -- to many -- important than "nuclear winter". The notion arises from the possibility that massive amounts of smoke which could be generated by thousands of fires following a nuclear holocaust could be transported long distances by the atmosphere and block solar energy from reaching the surface.

Nearly twenty five years ago a brief article appeared in the *Bulletin of the Atomic Scientists* warning of massive fires in the wake of nuclear blasts. Indeed, nuclear strategists had long debated whether blast or fire or radioactivity effects were the principal destructive mechanisms of nuclear warfare. And, there were a few very early attempts to estimate weather and climatic consequences of nuclear war in the 1960s. But none of these was based on sophisticated analyses and thus had very weak conclusions. They simply languished in relative obscurity.

Then in the early 1970s, the potential effects of stratospheric ozone depletion from nitrogen oxides produced by high-flying aircraft was independently discovered by atmospheric chemists Harold Johnston of the University of California, Berkeley and Paul Crutzen of the University of Stockholm, who was then a post-doctoral fellow at Oxford University in England. Since large nuclear blasts can inject massive amounts of these pollutants -- which can act as catalysts to destroy ozone -- into the stratosphere, the U.S. National Academy of Sciences (NAS) was asked by the U. S. Arms Control and Disarmament Agency to assess the long-term, world-wide consequences of nuclear war. However, although completely missing fires and some other important issues (see *The Coevolution of Climate and Life* for a longer history of this), the NAS report, which was published in 1975, did focus attention on a new global-scale element that might plague survivors in the aftermath of nuclear war: a drastic ozone reduction, lasting for at least several years.

In 1980, Ambio, the environmental journal of the Royal Swedish Academy of Sciences, commissioned a series of studies of nuclear war. One of those asked was Paul Crutzen, who was then Director at the Max Planck Institute for Chemistry in Mainz, West Germany. Crutzen was joined by chemist John Birks of the University of Colorado. Since Crutzen and Birks did know about the large fires that would likely be associated with nuclear attacks, it was logical to next examine the kinds of pollutants which big fires typically inject into the air. They eventually realized that the particles of soot and other materials in the smoke plumes from the forest fires alone would block out a substantial fraction of the sunlight, preventing it from reaching the lower atmosphere. The Crutzen-Birks study soon led to several national and international investigations of the atmospheric aftereffects of nuclear war.

To calculate climatic effects of unprecedented disturbances like a nuclear smoke cloud takes a climatic theory--actually a mathematical model of how the earth's climate works run in large computers. One group of NASA scientists--including two of astronomer Carl Sagan's former students--had already built a simple climate model to estimate the effects of a thick, high-altitude cloud of debris from a hypothesized collision between the earth and a giant asteroid some 65 million years ago, which physicist Luis Alvarez and coworkers speculated might have caused the extinction of the dinosaurs. Since the NASA scientists' model already existed, the tough remaining job was to extend the Crutzen-Birks estimate of how much smoke would get into the atmosphere. Atmospheric chemist Richard Turco reexamined the Crutzen-Birks calculations, and reduced their forest burning estimates; but he added a quantitative dimension to the main ingredient--smoke from burning cities. This, he estimated, would put several hundred million tons of sooty smoke high into the atmosphere, where it could last for at least weeks. Eventually the now-famous TTAPS (Turco, Toon, Ackerman, Pollack and Sagan) article appeared in which the term "nuclear winter" was coined, based on the continental-scale sub-freezing temperatures they calculated. The possibility that smoke or dust produced in the mid-latitudes of the Northern Hemisphere could be transported by its own heating out of the zone of injection was speculated on by Carl Sagan, based on an analogy to observations of Martian dust storms in which small regions of dust were sometimes seen to rapidly spread about the planet. A companion paper by a group of 22 biologists led by Paul Ehrlich, a Stanford University biologist, concluded that the possible global spread of sooty smoke in high concentrations could cause decreased light levels and temperatures severe enough to induce massive extinctions, perhaps even of humans. These dramatic and controversial works published in late 1983 got world-wide media attention--unlike the Crutzen-Birks discovery. But attention also went to bitter critics like physicist Edward Teller, who attacked both TTAPS assumptions for smoke injection amounts and their very crude climatic model. The TTAPS assumptions about the soot input from burning cities after a major nuclear exchange was subsequently independently confirmed and extended by Crutzen and colleagues, who also pointed out the particular importance of fires in fossil fuel depots. These have a very large component of soot in their smoke plumes relative to most other materials found in urban areas, and thus the subsequent Crutzen calculations actually increased the smoke injection estimates over those made by TTAPS.

The TTAPS paper predicted 20 to 40 or more degrees C land surface cooling for up to many months from such nuclear smoke clouds. Although the authors were aware of many of their model's deficiencies, TTAPS was criticized, nonetheless, for a number of reasons. First, they used a so-called "one-dimensional radiative-convective" climatic model, whereas the real world is, of course, three-dimensional. TTAPS represents the first generation of climatic assessments of the effects of nuclear war. A set of second generation studies shortly followed, and within another year a third generation of work became available. The rate at which new climatic studies are being done is several per year. As a result, a number of TTAPS conclusions have been sustained, some contradicted, and yet other altogether new conclusions have been uncovered--as we'll explore soon.

The TTAPS model was applied to either an all-land or all-ocean planet, and neglected the important effects of heat transported from oceans to land which might ameliorate the land surface cooling from the nuclear smoke scenarios. Also, TTAPS used annually-averaged solar radiative input, ignoring potential effects of seasonality on the results. There are other criticisms that could also be directed to TTAPS, such as their neglect of interactions between perturbed atmospheric conditions and smoke transport and removal or their inability to treat important smaller scale effects, such as fire plumes and their role in creating thunderstorm-like clouds which might wash out some of the initial smoke before it got very far in the atmosphere. However, most of these latter criticisms apply as well to all climatic modeling of "nuclear winter" to date--although interactive smoke transport and removal calculations studies (the "third generation" mentioned above) have now been conducted at several national labs. But the first three difficulties mentioned above have been examined in the context of more complex, so-called "three-dimensional, general circulation models". Two such second generation studies have been published as of 1985, a Russian study by V. Alexandrov and S. Stenchikov (AS) and an American effort by C. Covey, S.H. Schneider and S.L. Thompson (CST) at the National Center for Atmospheric Research (NCAR).

The CST three-dimensional model results significantly modified the one-dimensional TTAPS findings. It, along with TTAPS and the Russian work, helped provide the scientific support needed to conduct several major national and international assessments of the overall "nuclear winter" problem, including a second U.S. National Academy of Sciences study of long-term atmospheric effects of nuclear explosions. CST used a scenario for a large-scale nuclear war-induced smoke cloud at the direct request of this National Academy of Sciences study panel then in progress.

Like TTAPS, CST found significantly reduced light and surface temperatures in mid-continental regions under the assumed high altitude sooty smoke cloud. CST also noted that the smoke could be lifted by its own heating into the stratosphere, where it then could more easily spread out of the war zone, at least in the summer or spring seasons. However, CST also found that the magnitude of surface cooling under the smoke cloud was comparable to TTAPS only in mid-continental areas and in the summer. Along west coasts, the cooling was perhaps a factor of ten less. Moreover, in the three-dimensional CST model there was a great seasonal dependence to the cooling--TTAPS and AS only made a mean annual calculation--with CST's land average temperature drops ranging from about half TTAPS in the summer to relatively little change in winter.

But the most important CST result was the discovery of the possibility that even a few days of dense smoke high overhead could drop surface temperatures on land below freezing, depending on location and meteorological conditions. Moreover, such a transient "quick freeze" could be exported by the lottery of wind directions--a sort of "weather roulette"--to almost anyplace in the war hemisphere, even if the overall size of the nuclear smoke cloud was many times less than hypothesized by TTAPS or the National Academy study.

This possibility of "quick freeze"--it is too soon to say how certain it is--is both scientifically interesting and has major policy implications of its own; and it also cancels one implication of TTAPS. TTAPS postulated the existence of a "threshold" for nuclear winter--at a "modest" 100 megaton war in which major city centers were struck by 1000 100-kiloton bombs. This scenario represents use of about 1% of global nuclear arsenals. The implication is that wars with total megatonnage above 100 megatons exploded on cities could "trigger" a nuclear winter. This threshold concept has led to conflicting policy implications. Whereas Carl Sagan had said it implies that nuclear weapons stockpiles need to be reduced on both sides by a factor of twenty or more in order to drop below the TTAPS "threshold", a U.S. Department of Defense official countered that the TTAPS threshold suggests that one side could launch a 99 megaton first strike on the other side, but the victims couldn't fire back without crossing the threshold. Fortunately, planners can stop thinking up such pathological "threshold" scenarios, because they only arise in the context of a one-dimensional model such as used by TTAPS. The three-dimensional models with more realistic regional geography and dynamics included show that it is more likely that there would be a spectrum of probabilities and consequences, ranging from a higher probability of transient quick freezes to a lower chance of a more devastating global-scale nuclear winter lasting for months--which was the scenario that so concerned the 22 biologists. (Indeed, these second generation results of CST have been largely sustained by the third generation of studies--in which smoke is interactively transported and/or removed by the model's internal processes--at NCAR, Los Alamos and Livermore Labs. Some of the very latest NCAR results are appended to this testimony as illustrations, thanks to the efforts of my colleague Starley L. Thompson.)

The largest uncertainties surrounding the long-term climatic effects of nuclear smoke clouds arise not from the climatic models themselves, but from the assumptions used to drive them. In particular, what no climatic model can explicitly calculate is the height to which a plume of smoke will rise over a city consumed by a firestorm. If the bulk of the smoke is injected above a few kilometers of height, then this smoke will reside above the bulk of the water vapor in the atmosphere. The lifetime of the smoke, in turn, depends on how effective that water is in washing out the smoke. Thus, the biggest questions in the theory of "nuclear winter" occur at the local scale: namely, how much smoke will initially get how high. Then, how much smoke will be removed and spread by atmospheric motions in the next few days, as hundreds of plumes of smoke follow twisted paths over distances of a few hundred kilometers--the so-called "mesoscale" problem. If, as Crutzen and Birks, TTAPS, the 1985 NAS Report, AS or CST assumed, there is still some few hundred million tons of smoke spread high in the atmosphere after a week or so "post-war", then the likelihood of severe climatic effects on a hemispheric to global scale is high. On the other hand, if there were a great deal more initial washout of smoke arising from either lower plume heights or more rainfall than is presently anticipated, then the likelihood for global-scale "nuclear winter" would be lower, although the possibility of transient "quick freezes" would remain. It is simply too soon to have any quantitative way to estimate these relative probabilities, although there have been both some theoretical and experimental evidence that can be brought to bear to try to estimate how much smoke might get how high in the first few hours following the exchange of many nuclear weapons on a variety of targets.

In addition to the few cases of World War II firestorms there have been observations of large forest fires. The best documented one took place in Alberta, Canada in the summer of 1950. The smoke plume from this fire could be clearly traced for days, and was so dense that when it passed over Cleveland and Detroit on Sunday September 24, 1950, it darkened the sky to the point that lights were needed for afternoon baseball games. Temperatures were also several degrees below the expected levels in Washington, DC. This same cloud was observed by a Royal Air Force pilot over England several days later at a height of 9-12 kilometers! Clearly, when meteorological conditions permit, smoke from massive fires can both get very high and last a long time in the atmosphere.

SOME IMPLICATIONS

Suppose that nuclear winter is a real possibility, and it is accepted as such by nuclear strategists on both sides. However, suppose also, that for some scenarios the climatic aftereffects are believed to be markedly worse for one side than the other. If this were to be accepted by planners, then such a "nuclear winter" scenario could actually increase the probability of nuclear war, for it would imply an "advantage" to one side. Despite this possibility, I believe it is unlikely that "nuclear winter" research itself will increase the probability of war. For example, to date no research groups have reported any smoke and dust aftermath scenario which leaves one side with a clear advantage. Everything produced so far makes the impact of nuclear war on both sides worse--from marginally so to catastrophically so (to say nothing of the non-combatants!). Moreover, even if research could uncover some cases where one side seemed to be much less damaged by the ensuing smoke and dust clouds than the other side, there are simply too many uncertainties in the chain of events that starts with a scenario of warfare and ends up with the transport of uncertain quantities of smoke by winds around the planet to have much confidence in any such detailed scenario.

Miscalculation and uncertainty conspire against the credibility of any individual prediction of climatic aftereffects of a large-scale nuclear war. In other words, although we may have considerable confidence in the general statement that a spectrum of negative aftereffects is possible--even likely--no confidence can be given by anyone knowledgeable in the issues that any single chain of events would transpire. In fact, there is a very good chance that unforeseen consequences would occur. Thus, if one side attempted to fight a particular nuclear war that might give them a climatic "advantage" when the explosions were over, they would do so at a considerable risk that miscalculation could put them in an unforeseen disadvantageous position. There is, quite simply, a significant probability that climatic aftereffects will be worse for both sides than the chance that such aftereffects will give one side a meaningful edge that could tempt them to start pushing buttons. At least, that is what I and most of my colleagues currently believe.

No question could be more important in our times: How can we reduce the probability that any of this will ever happen? To do that, some say freeze new weapons deployment, others want more weapons deployed--so-called "peace through strength"--ostensibly to get fewer weapons later on, and yet others want different kinds of weapons systems. Among the latter are the so-called "Star Wars" defense systems or "penetrator" missiles that burrow into the enemies' hardened targets to replace those missiles now deployed. Presently deployed missiles are set to explode at the surface or in the air, which would cause the raising of dust and smoke into the atmosphere that has led to the concern over "nuclear winter" in the first place. Indeed, if we--or they--altered existing technologies or targeting policies to deliberately avoid starting big fires or kicking up lots of dust, then this step could make a big difference in helping to prevent a "nuclear winter". But, such a policy (of shifting targeting or replacing existing missiles with penetration) could also make nuclear war itself more thinkable, and thus perhaps more probable, even if less devastating initially. And who is to guarantee that the "losers" of such a limited exchange of penetrator warheads wouldn't, out of a sense of desperation, throw what nuclear weapons they had left at many of the same old targets (i.e., cities)? (And for the foreseeable future both sides will have plenty left--enough to assure the virtual destruction of any meaningful post-war civilization for the opponent as well as enough to raise tens of millions of tons of dust, smoke and toxic chemicals into the atmosphere.) Thus, any attempts to circumvent the risks of "nuclear winter" by purely technical fixes would likely create yet another set of dangers.

To me, what "nuclear winter" represents, then, is an opportunity to reexamine the policies--indeed, the mindset--that made this newest category of potential horrors so prominent. That mindset, I believe, is based on a combination or factors, ranging from real or imagined fears of a potential adversary's strength or intentions, to the belief that one's own security is enhanced by being the first to have new weapons systems, to the simple greed of those who benefit financially or professionally from the production or deployment of massive numbers of new or existing weapons systems. If the "nuclear winter" discoveries can help lead to a reexamination of the efficacy of these factors, it could have a major impact on the probability of nuclear war.

But "nuclear winter" is not a proved entity, only plausible theory. How then, some ask, could policy be made on the basis of all that uncertainty? For instance, although there are examples of lots of smoke getting into the atmosphere from historical fires, some of the most fundamental issues such as how much smoke will initially get how high and will spread how far from a thousand burning cities can never be definitively estimated--even by our most sophisticated computer models--until lots of real cities burn. In other words, some elements of the theory of nuclear winter may be unverifiable.

In response, others point out that military and strategic planning is based on scenarios of political or military conflicts with probabilities well below that for "nuclear winter", and that uncertainty is an unavoidable element of all strategic planning. The more relevant question, they would argue, is whether the world can afford to take the risk of experiencing "nuclear winter" without some anticipatory steps to reduce its chance of occurrence. To be sure, the large research programs now being considered in the U.S. and elsewhere can certainly help to narrow uncertainties and thus put nuclear winter-related decisionmaking on a firmer factual basis--unfortunately, prospects for significant new funds in this area do not seem high in the current budgetary climate. But at what stage does "uncertainty"--that venerable excuse to delay actions--become a ploy to avoid changing some current policies? These are the kinds of arguments that have accompanied the scientific findings on "nuclear winter".

What "nuclear winter" issues add to the arms control debate, in my opinion, is an extension to the global scale of the already well-traveled conclusion that use of even a small fraction of strategic nuclear weapons as now deployed would likely be mutual suicide. Additionally (see the appended figures for some specific examples), if even as little as one-third of the "baseline" smoke levels postulated by the National Academy of Science's recent study were deposited over the U.S. or the U.S.S.R. alone--that is, were there a "successful" first strike--there would be drifting clouds of smoke in the atmosphere that could pass over the territory of the attacker. The third generation of studies now becoming available suggests that such a "first-strike feedback scenario" could cause significant near freezing outbreaks in the summer in the Northern Hemisphere for weeks, including the territories of the U.S. and the U.S.S.R., regardless of whether the attacked country fired back. Finally, nuclear winter also warns any non-combatant nations or terrorist groups that any deliberate attempts to start a superpower nuclear war will not leave them immune from devastating consequences. The implications of these potential effects on non-combatants could have consequences on their attitudes towards the nuclear non-proliferation treaty renewal discussions that are imminent.

For all the reasons given, I believe that it is not premature to consider the implications of "nuclear winter" research to date for a host of applications. To be sure, large uncertainties remain, but many fundamental concerns over the potential climatic consequences of nuclear war have been sustained over three generations of increasingly complex investigations. As long as the nuclear winter scenarios are viewed probabilistically, there is no "scientific" logic in delaying such policy-oriented inquiries.

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Notes on the Figures

The following figures show results from computer model simulations done at the National Center for Atmospheric Research by Dr. Starley L. Thompson. The model used is a global climate model that calculates such quantities as wind, temperature and humidity on a three dimensional grid covering the Earth. Unlike earlier climate model studies, these simulations allow the winds to move the smoke produced by a nuclear war. However, the removal of smoke by rainfall is not included.

Research on the atmospheric effects of nuclear war at the National Center for Atmospheric Research is partially sponsored by the Defense Nuclear Agency.

Figure 1. The regions over which smoke is placed in the global climate model "Baseline" case are shown in black. The amount of smoke injected into the atmosphere is assumed to be 180 million metric tons following the National Academy of Sciences report released in December 1984, *The Effects on the Atmosphere of a Major Nuclear Exchange*. The smoke is injected over a period of two days between the surface and an altitude of 7 kilometers.
(Source: Starley L. Thompson, National Center for Atmospheric Research, 1985).

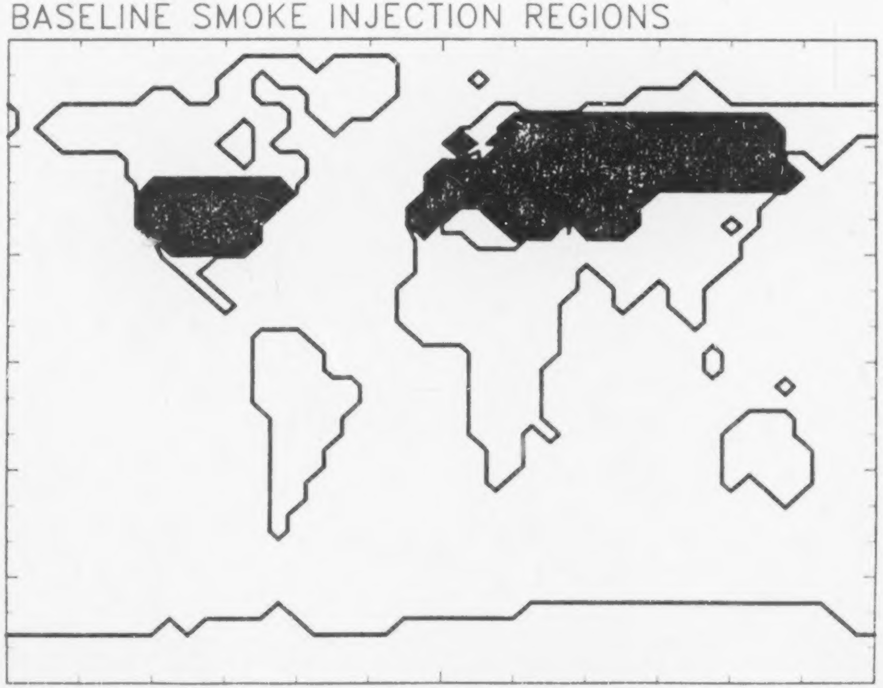


Figure 2. The July surface temperature in degrees Celsius just before the start of smoke generation. Note that below freezing temperatures in the Northern Hemisphere are confined to the areas bordering the Arctic Ocean.
(Source: Starley L. Thompson, National Center for Atmospheric Research, 1985).

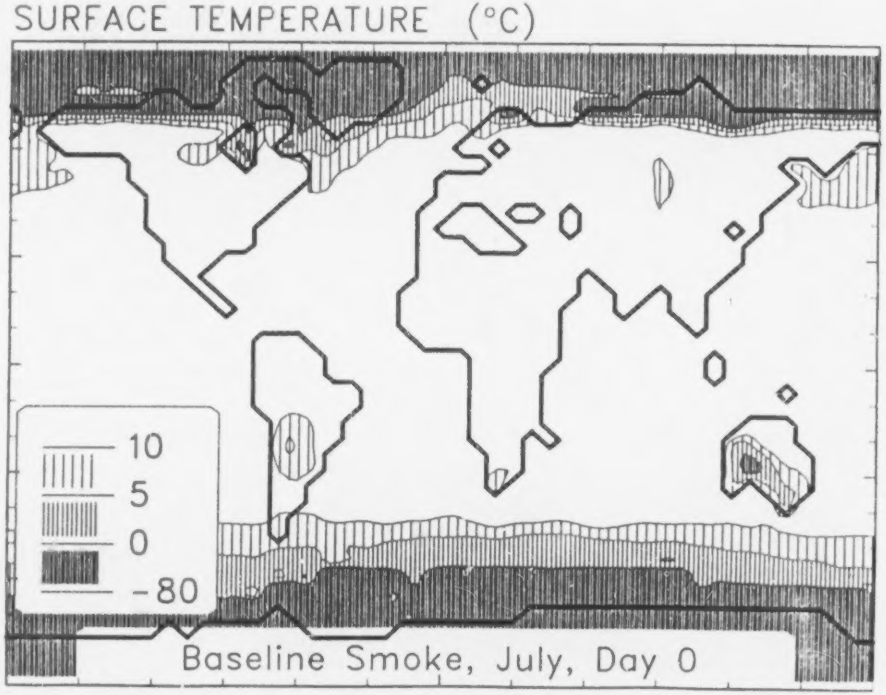

SURFACE TEMPERATURE (°C)
10
5
0
-80
Baseline Smoke, July, Day 0

Figure 9. The July surface temperature in degrees Celsius 10 days after the start of smoke generation. Sub-freezing temperatures are widespread in Europe and Asia, and extend as far south as the United States Gulf of Mexico coastline in North America. The patchy distribution of sub-freezing temperatures is a combined consequence of a patchy smoke distribution and normal day-to-day weather variability. (For comparison, see Figure 4.)
(Source: Starley L. Thompson, National Center for Atmospheric Research, 1985).

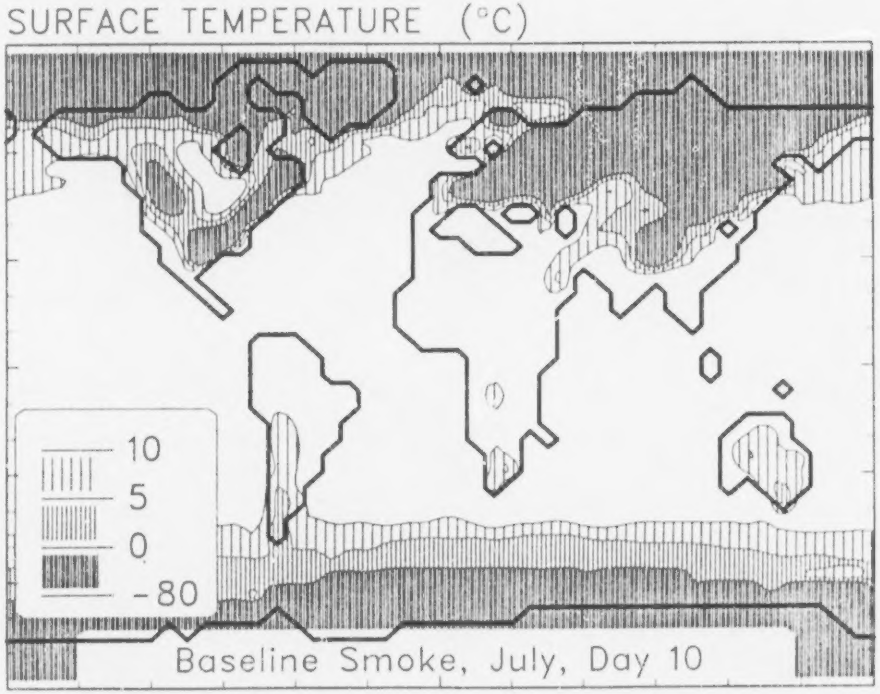

SURFACE TEMPERATURE (°C)
10
5
0
-80
Baseline Smoke, July, Day 10

Figure 4. The July surface temperature in degrees Celsius 20 days after the start of smoke generation. Note the change in the temperature pattern from day 10 (Fig. 3), especially over the U.S. and southern Asia. Smoke has now spread well into the tropics causing temperature drops in the Middle East, East Africa and northern South America, although temperatures in these regions remain above freezing.
(Source: Starley L. Thompson, National Center for Atmospheric Research, 1985).

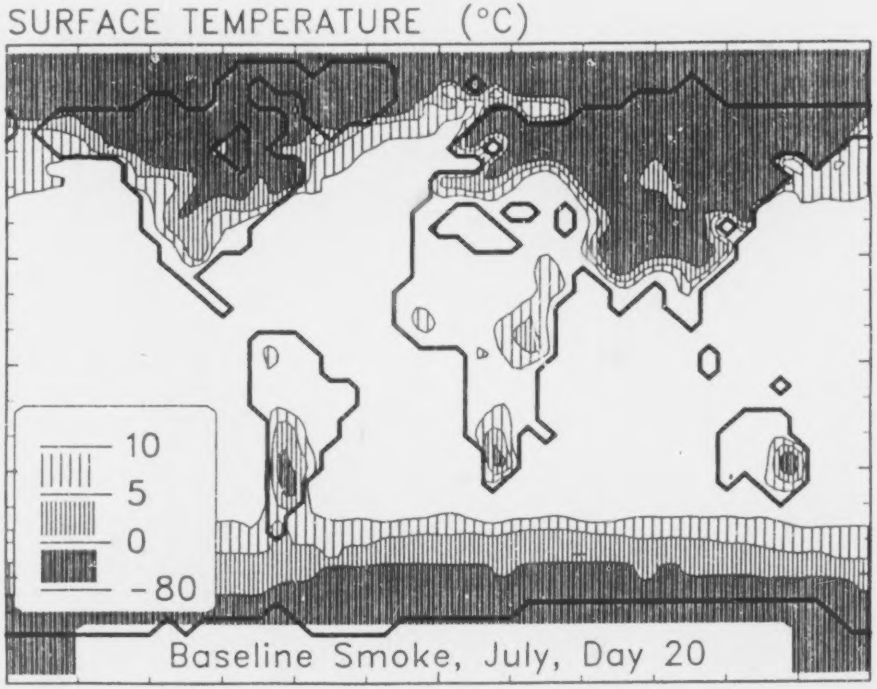

SURFACE TEMPERATURE (°C)
10
5
0
-80
Baseline Smoke, July, Day 20

Figure 5. The July surface temperature in degrees Celsius 15 days after the start of smoke generation for a case in which 60 million metric tons of smoke is injected. (This is 1/3 the baseline smoke amount.) Potential harmfully cold temperatures cover a smaller area than in the baseline case, but remain over northern North America, Europe and Asia.
(Source: Starley L. Thompson, National Center for Atmospheric Research, 1985).

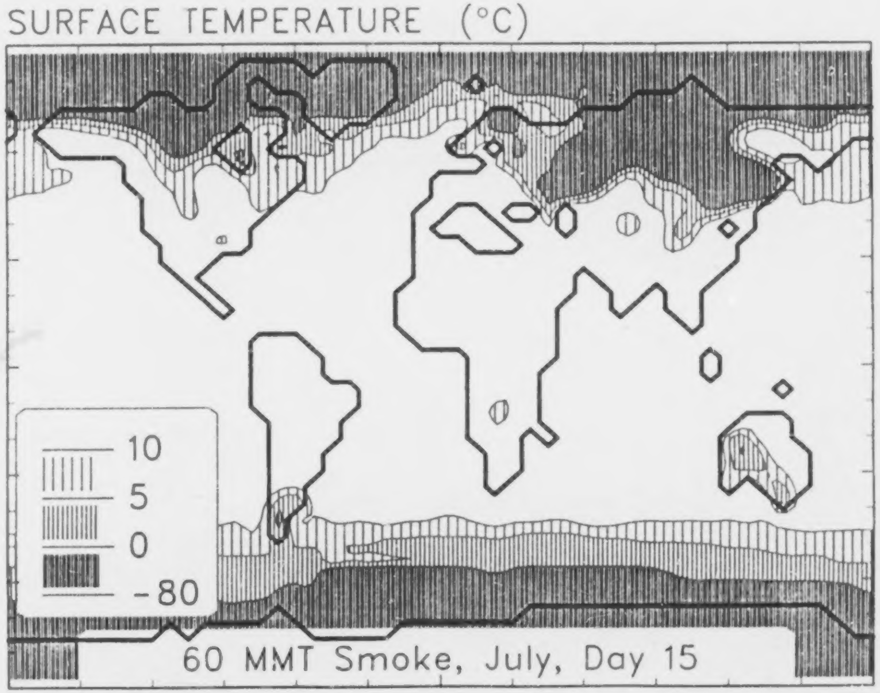
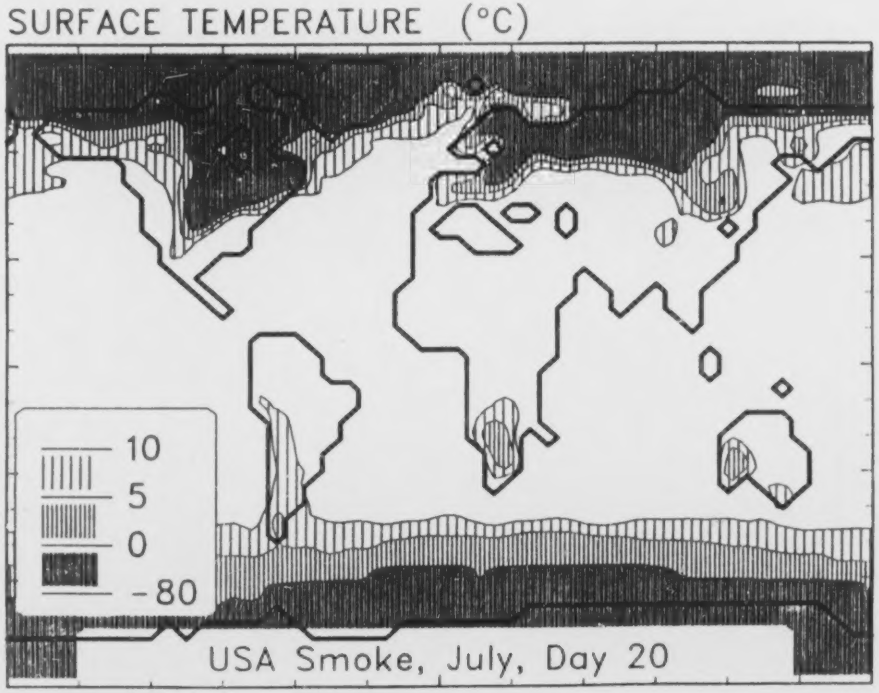

SURFACE TEMPERATURE (°C)
10
5
0
-80
60 MMT Smoke, July, Day 15

Figure 6. The July surface temperature in degrees Celsius 20 days after the start of smoke generation for a case in which 90 million metric tons of smoke is injected over the United States only. This case is intended to examine the effect of a massive Soviet nuclear strike against the U.S. with no U.S. nuclear retaliation. The movement of smoke around the northern hemisphere produces damaging temperatures not only in North America, but in large areas of Europe and the Soviet Union as well.
(Source: Starley L. Thompson, National Center for Atmospheric Research, 1985).



Mr. **Scheuer** [presiding]. Thank you very much, Dr. Schneider. That completes the presentations of the panel.

Congressman Wirth.

Mr. **Wirth**. Thank you, Mr. Chairman. And I thank all of you for your extraordinary patience. I think you also understand what it's like to be a younger Member of the Congress, while everybody at the top of the panel questions first and you come last. Seniority looks better to us all the time, as you can tell.

Let me ask you a couple of questions, and I might start with you, Dr. Stone and go down, and you can respond or not if you want.

The first question is, does the—the first question is, is the Pentagon's response to the amendment drafted last year and attached to the defense appropriation bill, is that response adequate and, if not, what should be added? That's question No. 1.

Question No. 2, and you may—you may have a reaction or you may not, is the amount of research funding adequate to the task, particularly that which is in the NSF, or would be done by independent researchers. Maybe you all could run down with a quick reaction to that double question.

Dr. **Stone**. I pass on the second question. But on the first question, Congressman Wirth, I think there is no reference, as far as I can tell, in the report to reviewing the war plans with regard to this new imperative suggested by nuclear winter of avoiding attacks on cities. A new reason has been given in our own interests of avoiding attacks on cities. And this is not referred to in any way in the report, even though, of course, you've asked for strategic implications.

Mr. **Wirth**. Yes.

Dr. **Stone**. Even—I would just add one sentence to this. In October 1980, there was a government directive that abandoned the requirement that we be able to destroy 70 percent of Soviet economic recovery and war-supporting assets. This is the category, of course, in which we do attack cities. We don't attack cities per se, but we target the areas in which there is industry and economic support.

The requirement that we be able to destroy 70 percent of that economic industry and war support was dropped in 1980, but according to the best observer I know of the war plans, Desmund Ball, he said in an important article, "It still remains the case that the top 300 urban industrial areas in the Soviet Union will continue to receive about the same amount of nuclear firepower and to suffer about the same amount of damage," as they would have before. That means that we are targeting most of the 300 largest cities in the Soviet Union. And since I'm not sure that's necessary for deterrence and since it could be very much not in our interest to fire at those cities, I think the war plan should be reviewed with regard to whether we've considered this new element, and I think a major effort should be mounted to persuade the Soviet Union that changes in their war plans and in their war plan options are in order, even though it can't be verified by the two sides.

Mr. **Wirth**. Thank you.

Dr. Brode.

Dr. **Brode**. My impression of the report on reading it was that it was fairly responsive, and I did not miss the lack of information about biological consequences since I was mostly concerned and interested in whether, in fact, the extent to which the phenomena was to occur or not was being treated adequately. Now I thought the report was fairly frank about that.

As far as the policy of city avoidance, which is certainly an easy thing to contemplate, I think when it comes to implementation with the actual targeting philosophy that's dictated by the Joint Chiefs of Staff and executed by the JSTPS in Omaha, it would mean a major change in their whole procedure, since a great deal—as Professor Stone has pointed out, a great deal of their targeting would have to be avoided or rethought as to the priorities. Many of those targets are urban targets, they're leadership targets, they're military targets, and they are urban-industrial type targets that would be inseparable from those urban areas.

If you recall, certainly the larger part of both Hiroshima and Nagasaki burned with very small yield weapons. We are talking about cities that are only several times larger being attacked with more than a single weapon of many times the yield. It would be difficult for any of those targets to be attacked without seriously damaging the rest of the city. So it would mean a great many of the targets on our target list would have to be reconsidered.

Mr. WIRTH. Dr. Rathjens.

Dr. RATHJENS. Well, on the response from the Defense Department, I would give it a very differentiated grade in contrast to Dr. Sagan. I think the first two parts which characterize the state of our knowledge are exceedingly well done and thought out. There's not all that much detail, but I think their—those two parts of the report are very good. And the last part is outrageously bad, the part that has to do with both policy and what might be done. And I think that I'd agree with Dr. Sagan, they should be sent back to do their homework. There are lots of kinds of tradeoffs that could be explored, that should be explored, for the committee.

Just to give you one example. They should look into the question of changing the SIOP to use more surface bursts and penetrating bursts, as Dr. Brode has suggested, to look and see how much fallout increases in order to reduce the amount of smoke by a given amount. Those are the kind of tradeoff analyses that have to be done to do anything meaningful in looking at possible changes in policy.

So, I have a very differentiated view as to the different parts of the report.

Now as to the budget, the allocation of resources to this problem, I don't know what to say. If you're going to take money from the aid to dependent children programs to spend more on research on this area, I wouldn't give it another nickel. And there are other social programs that I think are far more demanding of a few more million dollars than work on nuclear winter. On the other hand, if it's going to come out of the MX budget, I'd fund everybody I could find in Lafayette Park to do anything they wanted on it, and everybody else I could find. So my answer to that is this is a problem for you fellows, and the ladies, too. You got to—you're stuck with the problem of where's the money going to come from. If it's coming from social programs, I think we're spending more than enough on research on nuclear winter; if it's going to come from the DOD, I think there's a lot of money there that could be better spent than on weapons programs if it were spent on nuclear winter.

Mr. WIRTH. Thank you.

Mr. Williamson.

Mr. WILLIAMSON. I have to agree with George that the first two parts of the Pentagon's report are pretty good.

I would like to say that they ignore, or perhaps twist a bit, the last one, and that is—and so is this discussion. We're talking about essentially changing policies to make the world safe for nuclear war. I think that's very dangerous. I think it's extraordinarily dangerous to talk about a targeting philosophy that lets you think you can get away with it, because I don't think you're going to. I think that whatever happens, once you start with this particular form of war, escalation is going to occur and the results, whether nuclear winter or not, are going to be unacceptable, totally unacceptable. Emphasis, therefore, should not be on research to allow us to find soot-free targets. I think that is not a wise move.

I think to prove to ourselves there is no nuclear winter, which is a potential outcome of a lot of research, doesn't change the geopolitical equation. Obviously, it's a good scientific program. If it turns out to generate a worldwide weather model that we can trust, something that we spent 15 to 25 years trying to do but haven't gotten anywhere on because it hasn't had a nuclear or a military or something drive behind it, it's well worth it.

Mr. WIRTH. We can put some good atmospheric research in under the rubric of defense, and that would be worth the whole load; is that what you're suggesting, Mr. Williamson?

Mr. WILLIAMSON. Absolutely.

Mr. WIRTH. Thank you.

By the way isn't the argument that you make of looking at targeting or looking at making the world safer for nuclear war, the argument you were making earlier, exactly the same argument that one would make against SDI?

Mr. WILLIAMSON. No; the point about SDI, whether you believe in space lasers or not, is again a probabilistic question. Do you confuse the attack planner to the point he does not dare attack? You don't have to have a perfect defense. All you have to have is one that he thinks is going to screw up his planning.

Mr. WIRTH. So you're just saying the uncertainty factor is—we have a trillion dollars' worth of uncertainty going in?

Mr. WILLIAMSON. It doesn't matter whether you call it an SDI or a garage. If the guy attacking has to worry about something other than the weather and the fact his weapons are old and the fuses don't always work, you've doubled his problem.

Mr. WIRTH. Dr. Carrier.

Dr. CARRIER. I also think that the scientific—physical science part of the DOD report was excellent. It reflected the current state of knowledge very well.

I'm not qualified to talk on the policy parts of it.

As far as the budget's concerned, it seems to me that the general amount of money is probably what can sensibly be used at this stage of development. It has to be understood that it isn't going to be over with in 1 year, that there are going to be other questions that evolve out of this which have to be tackled. And as I said earlier, it will be done best if there's enough flexibility, and that means flexibility in the amount of funds, small increments from the total, so that as things arise, they can be attacked in a timely way rather than put off until the next budget cycle comes along.

Mr. SCHNEIDER. As to the adequacy of the report, I share most of my colleagues' views that it was two reports, and I will comment largely on the first one, not because I feel unqualified, but because I better not on the second one.

The first part of the report, the scientific part, I would agree that there are aspects of it that are very good. My complaint, which I stated before, is I felt that, although it was implicit, it would have been preferable had it been explicit that we're viewing the problem probabilistically. And probabilistically means that there are probabilities that things can happen, not that we shouldn't do anything because of this uncertainty. And I think that there's a distinction between uncertainty as an excuse to delay and uncertainty as to the exact nature of the details, not uncertainty that there would be things happening. And I would have preferred an emphasis—a greater emphasis on probability, although I felt the report was largely fair.

Critics of TTAPS, and of Carl Sagan in particular, have accused him of understating the uncertainties. I suppose one could say—with due respect to my DOD friends sitting over there—that perhaps the DOD report somewhat overstated the uncertainties, in my scientific opinion, but that, by and large, I feel it was a generally fair report in that regard.

The only other area that I was bothered with that it was missing is that what—what the low level of combat might mean for small amounts of fires and small amounts of smoke: theater war, first strike issues, and so forth, which didn't seem to me to be addressed on the scientific side. And there is a probabilistic way of—you know, at least one can probabilistically make some comments that perhaps there would be side effects from those. And I didn't see that there. Although, again, I don't think this calls for major expansion, but at least some recognition of those issues.

As I said earlier, in the second half of the report, I didn't see much about noncombatants. I don't know what we can say about that, about what other people's attitudes might be, but that somebody might investigate what—how that might influence either our policy or that of our adversaries.

As for the question of funding of research science, it's true that the amount of effort that we put in will never give us, no matter how much we do, detailed, complete, definitive ability to solve every problem, which I personally said I believe is good. But when you ask what will more funding do, you have to say for what. What funding does is it speeds up the rate at which the scientific community can increasingly give you credible statements about probabilities and consequences. So at the present level of funding, one just defers for a longer time the date at which such statements become increasingly in a probabilistic sense more credible.

For example, we've had at the National Center for Atmospheric Research some small help from the Defense Nuclear Agency, and what it's done is it's built on—it's built a great deal of leverage into our system, because we've been able to hire a few people to investigate parts of our modeling effort that we couldn't have done for many years, building on a very large effort that was already underway and getting high leverage from them and having us produce results at a faster rate. Obviously, more money means that we do that many more things faster.

But there are some aspects such as large-scale field experiments which may not have enough funding in it at present. You have to discuss that with DNA people and others to see just exactly how the plan that was put together by Alan Hecht in the National Climate Program Office with the help of many other agencies, how that plan could be implemented at the present level of funding. I'm skeptical that it could be done in terms of large experiments, but again you'll have to ask the others.

And finally, with regard to what George Rathjens said, does it—what does it do for our models and otherwise? The models that we use for nuclear winter studies are the same models we use for the carbon dioxide greenhouse effect, trace gases, Arctic haze, El Nino, and so forth, and the improvements that we make in that regard make those other problems more credible, too. So in a sense, the government isn't wasting its money, in my opinion, by improving them. But the real question is the rate at which you want to do that versus doing other things.

Mr. WIRTH. Gentlemen, thank you very much. We greatly appreciate your being here and your patience. I want to thank Mr. Udall and Mr. Scheuer for having such a thorough hearing and doing it so expeditiously. Gentlemen, thank you very much. Thank you.

Mr. UDALL. Mr. Scheuer.

Mr. SCHEUER. Thank you, Mr. Chairman.

Just one last question. On this business of certainty, we all act in our everyday lives in science, in politics, in business, in home, in our familes, with less than absolutely certitude. We very rarely have a 1.0 linear relationship between cause and effect. I mean, almost all doctors tell people not to smoke three cigarettes—three packs of cigarettes a day. But we don't have a linear relationship between smoking and lung cancer because you can't put people into a laboratory. We've never achieved that degree of scientific exactitude, although as a matter of judgment, it's perfectly clear that heavy smoking ain't good for you.

By the same criterion, it seems to me that while we haven't described nuclear winter with scientific precision and that there are all sorts of fuzzy parameters, that as a phenomenon, it's accepted, and the Defense Department has accepted it as something that's real out there.

Now the question is: What do they want to do about it? If you hear Secretary Perle, he seems to feel, well, it's real and it's there, but it hasn't changed anything very much, we still think SDI is the best deterrent factor, and we still believe that we have to avoid a nuclear confrontation of any kind. My question to you is: Does it change anything? How should—does it change the United States-Soviet Union deterrent relationship? How should the emergence of nuclear winter as a real force out there, as a real potential for incredible additional damage, how should that affect our thinking? How should that affect the negotiations that started this morning in Geneva? How should it be factored into our nuclear strategy thinking?

Mr. UDALL. Answer yes or no. [Laughter.]

Mr. WILLIAMSON. In absence of anyone else, I think you've touched on an important point, and that is that the U.S. policies tend to respond to U.S. citizens, so that if the American citizens share with you concern about this new and horrible phenomenon as perhaps changing the perceptions of nuclear war, then the policies that the United States would be likely to forward would take some change. If the Soviet Union does not have an identical view of the new danger and their policies do not change, the asymmetry, which I think Dick Perle mentioned, becomes one that is kind of expensive for the United States because it begins to attack, I think, the United States will to resist not nuclear war if it occurs, but the kinds of political posturings backed by the threat of war, which is backed by the threat of escalation to nuclear war, which the Soviets are very good at. And I think that is a reality that we have learned too much and cannot teach the other side the equivalent danger of the equivalent evil.

Mr. SCHEUER. Yes.

Mr. RATHJENS. I think you really asked two questions, and I'd like to address both. One is the question of how do you deal with uncertainty and risk in cases where you really don't know very much. And I think that the point that I would make is you do not do it by doing what we call worst case analysis when there is a large cost to be paid for hedging against that worst case. You have to take account of the real likelihoods.

Now let's take the nuclear winter phenomena. I believe it is not likely to be very serious, but it could be. I believe there's not a one chance in a million that the SDI kind of defense that the President has proposed is ever going to be very effective. But if I did the worst case analysis, and if there were no costs involved, I'd say let's go ahead with SDI. You know, it might be one chance in a million that it would work and it would prevent nuclear winter. I think that's absolutely crazy, because we'd be spending a trillion dollars on an insurance policy that probably would not be effective against a threat that is improbable. You just have to take into account the probability. There's no way—there's no way to avoid that. And to assume that—you assume the worst and then sort of say, well, because you might have a nuclear winter, you should behave as if it will happen, I think, is a grave error.

Now as to your second point, how it ought to affect Soviet-American relations in the negotiations that are going on. I submit it shouldn't affect them at all at this point in time, and I say that because it does seem to me the damage that the United States and the Soviet Union could expect to incur in any kind of a war, from blast effects, from disruption of transportation and starvation and all the other effects we've talked about for many years, are just so overwhelmingly large that I cannot imagine taking a different position on any kind of an issue in those negotiations because of the added effect of nuclear winter. And I would go even further. I would say I wouldn't imagine taking a different position even if I thought the probability of nuclear winter were very high. I happen to think it's low.

Mr. **Schneider**. Very briefly, in my own view of how nuclear winter affects things, the first thing I would have to say is the principal customer would be the noncombatants. I agree with George Rathjens and others before that things were bad enough among the combatants even without nuclear winter, and how noncombatants would view this and how it would affect our relations with them and others would really have to be considered further.

The second thing is—arguing probabilistically as I've done before—saying that there's a higher probability of lesser events. Those lesser events which could be transient quick freezes anywhere in the hemisphere could still be very serious for us or others. And then I feel that we have to more seriously consider those wars which are considered more probable, namely theater war or limited or possible first strikes. Where we're customers for a nuclear winter like information is on the shorter term or more believable wars.

And finally, the last—the last point about nuclear winter is there are those who believe in civil defense or who believe in survivability and, for them, it has a message for either limited or nonlimited wars. That would be a short answer.

Mr. **Scheuer**. Yes, Dr. Stone.

Dr. **Brode**. In discussing this—oh, I'm sorry, Professor Carrier.

Mr. **Carrier**. Thank you.

I was merely going to say that there is another way of dealing with uncertainty that is sometimes possible, and that is to reduce it to levels where the definitiveness of the statement that you can make is a worthwhile improvement, and that's what I think we ought to be about.

Dr. **Stone**. I think in this question of probability it's important to view nuclear winter not only as a specific problem, but also as a metaphor for all the other different things that we don't expect, as not long ago we didn't expect nuclear winter, but which might happen. And if you add together all of the things which we don't know about but might happen, I think there is a substantial likelihood that some of it will happen.

And in this regard, the 1975 study of the National Academy of Sciences talked not only about a major climatic change, but also talked about problems in the oceans, in the food chain and problems on the land. And as I understand Professor—Congressman Wirth's amendment, it's supposed to elicit from the Defense Department some study of other problems like biological ones that might arise independently, not only biological ones that would arise as a result of the cold and dark of nuclear winter. In that regard, as I understand the amendment, it's an attempt to pursue what was being pursued by the National Academy of Sciences in 1975, a broad-scale investigation into other unexpected things that might go wrong. If I'm right about that, then Secretary Perle is not, because I think he referred to the investigation of these other elements as being elements derivative to—to the problem of nuclear winter.

Finally, if I had to summarize what it seems to me is learned from this, we're reinforced in our view that there can be no victory in nuclear war, and we've discovered that there is a great common interest in there not being any revenge.

Mr. Scheuer. Tim, anything else?

Mr. Wirth. Again, let me thank you, gentlemen. Due to the late hour, we are even putting together a special transportation operation going out to Dulles Airport which will be leaving soon after here. If any of you would like to take advantage of that—Dr. Schneider is doing so—if any of you have to go to Dulles, hook up with Steve and we'll get you out there. Thank you all. Thank you all for being here.

Mr. Scheuer. Thank you again. It was a very thoughtful and stimulating panel. We're grateful to you.

[The closing remarks of Mr. Lujan follow:]

Hon. Manuel Lujan, Jr., Closing Remarks: Joint Hearing on Nuclear Winter, March 14, 1985

Mr. Chairman, this hearing today has dealt with a lot of theory. Hopefully, our experience with both nuclear war and nuclear winter will always be just that—theory—and never reality. But, I am concerned when a hearing on a serious subject becomes, instead, a forum for political views beyond the scope and theme of the hearing. We have heard a lot of cute quips and off-hand comments about this topic. Dr. Sagan gave us a lot of theory and much philosophy. Unfortunately, he did not deal with realistic ways to approach this problem. I feel the Administration is making a serious effort to deal with both the threat of nuclear war and the prospect of a nuclear winter. If that were not so, we would not be in Geneva right now trying to reach a serious arms control agreement. That, Mr. Chairman, is a real, practical approach to the problems which face us today. It is reality, not theory.

[Whereupon, at 1:15 p.m., the subcommittees were adjourned.]

APPENDIX

Additional Materials for the Record

SECRETARY OF DEFENSE

CASPAR W. WEINBERGER

DEPARTMENT OF DEFENSE UNITED STATES OF AMERICA

THE POTENTIAL EFFECTS OF NUCLEAR WAR ON THE CLIMATE

A REPORT TO THE UNITED STATES CONGRESS

MARCH 1985

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PREFACE

This report to the Congress on the potential climatic effects of nuclear war has been prepared to satisfy provisions contained in Section 1107 of the Department of Defense Authorization Act, 1985, Committee of Conference, as follows:

> "Sec. 1107 (a) The Secretary of Defense shall participate in any comprehensive study of the atmospheric, climatic, environmental, and biological consequences of nuclear war and the implications that such consequences have for the nuclear weapons strategy and policy, the arms control policy, and the civil defense policy of the United States.
>
> (b) Not later than March 1, 1985, the Secretary of Defense shall submit to the Committees on Armed Services of the Senate and House of Representatives an unclassified report suitable for release to the public, together with classified addenda (if required), concerning the subject described in subsection (a). The Secretary shall include in such report the following:
>
> > (1) A detailed review and assessment of the current scientific studies and findings on the atmospheric, climatic, environmental, and biological consequences of nuclear explosions and nuclear exchanges.
> >
> > (2) A thorough evaluation of the implications that such studies and findings have on (A) the nuclear weapons policy of the United States, especially with regard to strategy, targeting, planning, command, control, procurement, and deployment, (B) the nuclear arms control policy of the United States, and (C) the civil defense policy of the United States.
> >
> > (3) A discussion of the manner in which the results of such evaluation of policy implications will be incorporated into the nuclear weapons, arms control, and civil defense policies of the United States.
> >
> > (4) An analysis of the extent to which current scientific findings on the consequences of nuclear explosions are being studied, disseminated, and used in the Soviet Union."

This focus of this report deals with the atmospheric and climatic effects of nuclear war, and does not deal with other effects which could have environmental or biological consequences. Other effects, both the horrible immediate devastation, and long-term effects such as widespread fallout or ionospheric chemistry perturbations, have been dealt with previously. Moreover, the newly postulated climatic effects, at the possible upper extremes indicated by some analyses, would probably surpass these better understood effects.

On past occasions when other more immediate kinds of global effects have been under active assessment--and there have been several such episodes over the years--it took some time for their magnitude and implications to be assessed. This will also be true for the current issue of climatic effects. And in each previous case, the conclusion was drawn that, even were the effect to have been very widespread and very severe, the most basic elements of our policy remain sound: nuclear war must and can be prevented, and to accomplish this imperative, the United States must maintain a strong deterrent capability. This requirement remains true today. Moreover, there are two further considerations which bear on the issue of global effects of nuclear war and our deterrent policy. First, we believe the prospects are promising for significant reductions in offensive weapons. Second, strategic defense offers a path to reduce, and perhaps someday eliminate, the threat of nuclear devastation.

The report commences with a review of the current understanding of the technical issues, and then describes the implications of that understanding, concluding with a description of Soviet activities concerning the analysis of the phenomena.

THE POTENTIAL EFFECTS OF NUCLEAR WAR ON THE CLIMATE
A REPORT TO THE UNITED STATES CONGRESS

1. Technical Issues

The Climatic Response Phenomena: The basic phenomena that could lead to climatic response may be described very simply. In a nuclear attack, fires would be started in and around many of the target areas either as a direct result of the thermal radiation from the fireball or indirectly from blast and shock damage. Examples of the latter would be fires started by sparks from electrical short circuits, broken gas lines and ruptured fuel storage tanks. Such fires could be numerous and could spread throughout the area of destruction and in some cases beyond, depending on the amount and type of fuel available and local meteorological conditions. These fires might generate large quantities of smoke which would be carried into the atmosphere to varying heights, depending on the meteorological conditions and the intensity of the fire.

In addition to smoke, nuclear explosions on or very near the earth's surface can produce dust that would be carried up with the rising fireball. As in the case of volcanic eruptions such as Mt. Saint Helens, a part of the dust would probably be in the form of very small particles that do not readily settle out under gravity and thus can remain suspended in the atmosphere for long periods of time. If the yield of the nuclear explosion were large enough to carry some of the dust into the stratosphere where moisture and precipitation are not present to wash it out, it could remain for months.

Thus, smoke and dust could reach the upper atmosphere as a result of a nuclear attack. Initially, they could be injected into the atmosphere from many separate points and to varying heights. At this point, several processes would begin to occur simultaneously. Over time, circulation within the atmosphere would begin to spread the smoke and dust over wider and wider areas. The circulation of the atmosphere would itself be perturbed by absorption of solar energy by the dust and smoke clouds, so it could be rather different from normal atmospheric circulation. There may also be processes that could transport the smoke and dust from the troposphere into the stratosphere. At the same time, the normal processes that cleanse pollution from the lower-and middle-levels of the atmosphere would be at work. The most obvious of these is precipitation or washout, but there are several other mechanisms also at work. While this would be going on, the physical and chemical characteristics of the smoke and dust could change so that, even though they are still suspended in the atmosphere, their ability to absorb or scatter sunlight would be altered.

Depending upon how the atmospheric smoke and dust generated by nuclear war are ultimately characterized, the suspended particulate matter could act much like a cloud, absorbing and scattering sunlight at high altitude and reducing the amount of solar energy reaching the surface of the earth. How much and how fast the surface of the earth might cool as a result would depend on many of the yet undetermined details of the process, but if there is sufficient absorption of sunlight over a large enough area, the temperature change could be significant. If the smoke and dust clouds remained concentrated over a relatively small part of the earth's surface, they might produce sharp drops in the local temperature under them; but the effect on the hemispheric (or global) temperature would be slight since most areas would be substantially unaffected.

However, the natural tendency of the atmosphere, disturbed or not, would be to disperse the smoke and dust over wider and wider areas with time. One to several weeks would probably be required for widespread dispersal over a region thousands of kilometers wide. Naturally, a thinning process would occur as the particulate matter spread. At the end of this dispersal period, some amount of smoke and dust would remain, whose ability to attenuate and/or absorb sunlight would depend on its physical and chemical state at the time. By this time, hemispheric wide effects might occur. Temperatures generally would drop and the normal atmospheric circulation patterns (and normal weather patterns) could change. How long temperatures would continue to drop, how low they would fall, and how rapidly they would recover, all depend on many variables and the competition between a host of exacerbating and mitigating processes.

Uncertainties also pervade the question of the possible spread of such effects to the southern hemisphere. Normally the atmospheres of the northern and southern hemispheres do not exchange very much air across the equator. Thus, the two hemispheres are normally thought of as being relatively isolated from one another. However, for high enough loading of the atmosphere of the northern hemisphere with smoke and dust, the normal atmospheric circulation patterns might be altered and mechanisms have been suggested that would cause smoke and dust from the northern hemisphere to be transported into the southern hemisphere.

There is fairly general agreement, at the present time, that for major nuclear attacks the phenomena could proceed about as we have described, although there is also realization that important processes might occur that we have not yet recognized, and these could work to make climatic alteration either more or less serious. However, the most important thing that must be realized is that even though we may have a roughly correct qualitative picture, what we do not have, as will be discussed later, is the ability to predict the corresponding climatic effect quantitatively; significant uncertainties exist about the magnitude, and persistence of these effects. At this time, for a postulated nuclear attack and for a specific point on the earth, we cannot predict quantitatively the materials which may be injected into the atmosphere, or how they will react there. Consequently, for any major nuclear war, some decrease in temperature may occur over at least the northern mid-latitudes. But what this change will be, how long it will last, what its spatial distribution will be, and, of much more importance, whether it will lead to effects of equal or more significance than the horrific destruction associated with the short-term effects of a nuclear war, and the other long-term effects such as radioactivity, currently is beyond our ability to predict, even in gross terms.

Historical Perspective: New interest in the long-term effects on the atmosphere of nuclear explosions was raised in 1980 when scientists proposed that a massive cloud of dust caused by a meteor impact could have led to the extinction of more than half of all the species on earth. The concept of meteor-impact dust affecting the global climate led to discussions at the National Academy of Sciences (NAS) in 1981. In April 1982, an ad hoc panel met at the Academy to assess the technical aspects of nuclear dust effects. At the meeting, the newly-discovered problem of smoke was brought up. The potential importance of both smoke and dust in the post-nuclear environment was recognized by the panel, who wrote a summary letter recommending that the Academy proceed with an in-depth investigation. In 1983, the Defense Nuclear Agency agreed to sponsor this investigation, on behalf of the Department of Defense. The results were published in the National Research Council report "The Effects on the Atmosphere of a Major Nuclear Exchange," released in December 1984.

Appreciation of smoke as a major factor resulted from the work of Crutzen and Birks. In 1981, Ambio, the Journal of Swedish Academy of Sciences, arranged a special issue on the physical and biological consequences of nuclear war. Crutzen was commissioned to write an article on possible stratospheric ozone depletions. He and Birks extended their analysis to include nitrogen oxides (NO_x) and hydrocarbon air pollutants generated by fires. Arguing from historical forest fire data, they speculated that one million square kilometers of forests might burn in a nuclear war. They estimated very large quantities of smoke would be produced as a result. Subsequent evaluations based upon hypothetical exchanges have yielded much smaller burned areas and smoke production. Nevertheless, their work provided insight and impetus for subsequent studies.

The first rough quantitative estimates of the potential magnitude of the effects of nuclear war on the atmosphere were contained in a paper published in Science in December 1983(1) generally referred to as TTAPS, an acronym derived from the first letter of the names of the five authors. This study estimated conditions of near-darkness and sub-freezing land temperatures, especially in continental interiors, for up to several months after a nuclear attack--almost independent of the level or type of nuclear exchange scenario used. TTAPS suggested that the combination of all of the long-term physical, chemical, and radiobiological effects of nuclear explosions could, on a global scale, prove to be as serious or more serious than the immediate consequences of the nuclear blasts, although no specific damage or casualty assessments were carried out for either the immediate effects or the effects of the postulated climatic changes.

While the Crutzen and Birks studies stirred some interest in scientific circles, the TTAPS study, and its widespread dissemination in various popular media, brought the problem to wide public attention. Because of its widespread dissemination, it is important to review this work in detail, and, because the salient feature of our current understanding is the large uncertainties, we will begin by discussing the nature of the uncertainties, using the TTAPS study as a vehicle for the discussion.

Uncertainties: The model used in the TTAPS study was actually a series of calculations that started with assumed nuclear exchange scenarios and ended with quantitative estimate of an average hemispheric temperature decrease. Since these phenomena are exceedingly complex and outside the bounds of our normal experience, one is forced to employ many estimates, approximations, and educated guesses to arrive at quantitative results. To appreciate the significance of the predictions derived from the TTAPS model, it is necessary to understand some of its features and limitations.

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(1) Turco, R. P. et al.; Nuclear Winter: Global Consequences of Multiple Nuclear Explosions; Science, 23 December 1983, VOL 222, Number 4630.

Looked at most broadly, there are three phases to the modeling problem: the initial production of smoke and dust; its injection, transport, and removal within the atmosphere; and the consequent climatic effects.

In the TTAPS model, the amount of smoke initially produced for any given scenario was probably the most uncertain parameter. This is because a large number of poorly-known variables were combined to determine the amount of smoke that could be produced from any single nuclear explosion. In actuality, the same yield weapon could produce vastly different amounts of smoke over different target areas and under different meteorological conditions. Some of the factors that must be considered--although not taken into account in the TTAPS study--include: the thermal energy required for ignition of the various fuels associated with a particular target area, the sustainability of such a fire, the atmospheric transmission and the terrain features which will determine the area receiving sufficient thermal energy from the fireball to cause ignition, the type and quantity of combustible material potentially available for burning, the fraction that actually burns, and finally, the amount of smoke produced per unit mass of fuel burned. Every target is unique with respect to this set of characteristics, and a given target may change greatly depending on local weather, season, or even time of day.

The TTAPS study did not attempt to analyze the individual targets or areas used for their various scenarios; rather, it made estimates of average or plausible values for all the parameters needed to satisfy the model. This procedure is not unreasonable and is consistent with the level of detail in the analysis, but the potential for error in estimating these averages is clearly quite large. In one case, a more detailed assessment of smoke production has recently been completed as a result of the ongoing DoD research in this area. Small and Bush(2) have made an analysis of smoke produced as a result of hypothetical non-urban wildfires which one can directly compare with the corresponding modeling assumption used in this TTAPS scenario. Bush and Small studied 3,500 uniquely located, but hypothetical targets, characterizing each according to monthly average weather, ignition area, fuel loading, fire spread, and smoke production. The results showed a significantly smaller smoke production--by a factor of over 30 in July to almost 300 in January--than comparable TTAPS results. An effort is underway to resolve this great difference. It is cited here to illustrate the very large current uncertainties in only one of several critically important parameters.

In the TTAPS analysis, smoke was more important than dust in many cases, and as a result popular interest has tended to focus on fires rather than dust. This may or may not be the correct view. If smoke is systematically overestimated, especially in scenarios that should emphasize dust production over smoke (such as attacks on silos using surface bursts), analytic results will be skewed. Additionally, uncertainties associated with the lofting of dust are large because of limited data from atmospheric nuclear tests carried out prior to 1963. This is because most tests were not relevant to the question of surface or near-surface bursts over continental geology, or the relevant measurements were not made. The range of uncertainty for total injected mass of submicron size dust, that which is of greatest importance, is roughly a factor of ten, based on our current knowledge.

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(2) Small, R.D., Bush, B. W.; Smoke Production from Multiple Nuclear Explosions in Wildlands; Pacific Sierra Research Corporation, in publication.

After generation of smoke and dust is estimated, a model must then portray its injection into the atmosphere, the removal processes, and the transport both horizontally and vertically. The TTAPS model did not directly address these processes since it is a one-dimensional model of the atmosphere. By one-dimensional, one means that the variation of atmospheric properties and processes are treated in only the vertical direction. There is no latitudinal or longitudinal variation as in the real world. A one-dimensional model can only deal with horizontally averaged properties of the entire hemisphere. Of great significance, the land, the oceans, and the coastal interface regions cannot be treated. This is a critical deficiency because the ocean, which covers almost three-fourths of the earth's surface, has an enormous heat capacity compared to the land and will act to moderate temperature changes, especially near coastlines and large lakes. The TTAPS authors did acknowledge this limitation and pointed out that these effects would lessen their predicted temperature drops.

Because there is no horizontal (latitude and longitude) dependence in a one-dimensional model, the extent to which smoke and dust would be injected into the atmosphere over time were not estimated in a realistic way. Instead, the total smoke and dust estimated for a given scenario was placed uniformly over the hemisphere at the start of their calculation. The most certain effect of all this is that the hemisphere average temperature drops very rapidly--much faster than it would in a more realistic three-dimensional model using the same input variables.

The one-dimensional model has other shortfalls. Recovery from the minimum temperatures would largely be accomplished through the gradual removal of smoke and dust, and it was assumed that this removal rate would be the same in the perturbed atmosphere as it is in the normal atmosphere. Even in the normal atmosphere, removal of pollutants is a poorly understood process. Most pollution removal depends on atmospheric circulation and precipitation, but in an atmosphere with a very heavy burden of smoke and dust, the circulation and weather processes may be greatly altered. Some potential alterations could lead to much slower removal than normal, others to more rapid removal. Currently we have little insight into this uncertainty.

This discussion of the deficiencies of the one-dimensional TTAPS model is not meant as a criticism. A one-dimensional model is a valuable research tool and can provide some preliminary insights into the physical processes at work. The three-dimensional models needed to treat the problem more realistically are exceedingly complex and will require very large computational resources. The DoD and Department of Energy, in conjunction with the National Center for Atmospheric Research (NCAR) and other agencies, are pursuing the development of three-dimensional models to treat the atmospheric effects problem. Our work is progressing, and the first results of this effort are now beginning to appear. Though very preliminary and not a complete modeling of any specific scenario, they suggest that:

- Substantial scavenging of smoke injected into the lower atmosphere from the continents of the Northern Hemisphere may occur as the smoke is being more widely dispersed over the hemisphere.

- Lofting of smoke through solar heating could act to increase the lifetime of the remaining smoke and may reduce the sensitivity to height of injection.

- For very large smoke injections, global-scale spreading and cooling are more likely in summer than in winter.

Despite good initial progress, many basic problems remain to be solved in the areas of smoke and dust injection, transport, and removal. In order to make the results produced by these models more accurate, we must improve our understanding of the basic phenomena occurring at the micro, meso, and global scale.

One final problem should be mentioned. Dust and smoke have differing potentials to effect the climate only because of their ability to absorb and scatter sunlight. The absorption and scattering coefficients of the various forms of smoke, dust, and other potential nuclear-produced pollutants must be known before any realistic predictions can be expected. Here again there is a large uncertainty, and what we do know about pollutants in the normal atmosphere may not be correct for the conditions in a significantly altered atmosphere.

National Academy of Sciences Report, 1984: Following their preliminary review of the possible effects of nuclear war-induced smoke and dust in April 1982, the NAS came to an agreement with DNA, acting on behalf of the DoD, to support a full-fledged study. The first committee meeting occurred at the NAS in March 1983. The NAS committee adopted the one-dimensional TTAPS analysis as a starting point for their investigation. During the course of the study, virtually all of the work going on pertinent to this phenomenon was reviewed.

The result of this effort was the NAS report, "The Effects on the Atmosphere of a Major Nuclear Exchange," released on December 11, 1984.

The conclusion of the report states that:

> ". . . a major nuclear exchange would insert significant amounts of smoke, fine dust, and undesirable species into the atmosphere. These depositions could result in dramatic perturbations of the atmosphere lasting over a period of at least a few weeks. Estimation of the amounts, the vertical distributions, and the subsequent fates of these materials involves large uncertainties. Furthermore, accurate detailed accounts of the response of the atmosphere, the redistribution and removal of the depositions, and the duration of a greatly degraded environment lie beyond the present state of knowledge.
>
> "Nevertheless, the committee finds that, unless one or more of the effects lie near the less severe end of their uncertainty ranges, or unless some mitigating effect has been overlooked, there is a clear possibility that great portions of the land areas of the northern temperate zone (and,

perhaps, a large segment of the planet) could be severely affected. Possible impacts include major temperature reductions (particularly for an exchange that occurs in the summer) lasting for weeks, with subnormal temperatures persisting for months. The impact of these temperature reductions and associated meteorological changes on the surviving population, and on the biosphere that supports the survivors, could be severe, and deserves careful independent study.

". . . all calculations of the atmospheric effects of a major nuclear war require quantitative assumptions about uncertain physical parameters. In many areas, wide ranges of values are scientifically credible, and the overall results depend materially on the values chosen. Some of these uncertainties may be reduced by further empirical or theoretical research, but others will be difficult to reduce. The larger uncertainties include the following: (a) the quantity and absorption properties of the smoke produced in very large fires; (b) the initial distribution in altitude of smoke produced in large fires; (c) the mechanism and rate of early scavenging of smoke from fire plumes, and aging of the smoke in the first few days; (d) the induced rate of vertical and horizontal transport of smoke and dust in the upper troposphere and atmosphere; (e) the resulting perturbations in atmospheric processes such as cloud formation, precipitation, storminess, and wind patterns, and (f) the adequacy of current and projected atmospheric response models to reliably predict changes that are caused by a massive, high altitude, and irregularly distributed injection of particulate matter. The atmospheric effects of a nuclear exchange depend on all of the foregoing physical processes ,(a) through (e)., and their ultimate calculation is further subject to the uncertainties inherent in (f)."

The Interagency Research Program (IRP): The genesis of this program stems from ongoing DoD and DoE research efforts. In 1983, both the DoD and the DoE started research on the atmospheric response phenomena. In addition to sponsoring the NAS study just discussed, the DoD portion of the program addressed a broad range of issues associated with the long-term global climatic effects of nuclear exchange. This program ($400K in FY83, $1100K in FY84, $1500K in FY85, $2500K in FY86 and continuing at appropriate levels into the future) supports research on several fronts--at numerous government laboratories, universities, and contractors.

The DoD portion of the IRP emphasizes research in (1) the smoke and dust source terms, including the definition of total ignition area, fuel loading and fire spreading, and particulate production, (2) large-scale fire characteristics, particulate lofting, scavenging, coagulation, rain-out, and atmospheric injection, (3) chemistry, including the chemical kinetics of fires and fireballs, the chemical consequences of mesoscale and global processes, and radiative properties (optical and infrared absorption, emission, and scattering), and (4) climatic effects, including the improvement of mesoscale and global climate models to incorporate better particulate source functions; horizontal advection processes; vertical mixing; solar radiation; particulate scavenging; inhomogeneities; particulate, radiative, and circulation feedbacks; seasonal differences; and particulate spreading.

The effort supported by the DoE is fully coordinated with that of the DoD and is currently funded at roughly $2M per year. The LLNL program is broad-based and includes modeling of urban fire ignition, plume dynamics, climate effects, radioactive fallout, and biological impacts. The LANL program focuses on developing comprehensive models for global-scale climate simulations. It is coordinated with complementary efforts at NCAR and NASA Ames. The IRP came into being with approval of the draft Research Plan for Assessing the Climatic Effects of Nuclear War prepared by a committee of university and government scientists. The plan was initiated by Presidential Science Advisor, Dr. George Keyworth, with the National Climate Program Office of NOAA heading the preparation effort. This program augments and coordinates the research activities currently underway in the DoD and the DoE with other government agencies. The program focuses particularly on the problems of fire dynamics, smoke production and properties, and mesoscale processes. The proposed additional research includes increases in theoretical studies, laboratory experiments, field experiments, modeling studies, and research on historical and contemporary analogues of relevant atmospheric phenomena.

The IRP recognizes the need for expertise from a number of experts inside and outside of the Federal Government--many are already at work on the problem. Participating government agencies would include the Department of Defense (DNA), Department of Energy, National Oceanic and Atmospheric Administration (NOAA), National Science Foundation (NSF), National Bureau of Standards, National Aeronautics and Space Administration (NASA), Federal Emergency Management Agency (FEMA), and the U.S. Forest Service. The IRP Steering Group is chaired by the President's Science Advisor and is composed of representatives from the Department of Defense, Department of Energy, Department of Commerce, and the National Science Foundation.

The major goals of the IRP are to accelerate the research to reduce the numerous uncertainties in smoke sources and to improve modeling of atmospheric effects. Although it is recognized that not all of the uncertainties could be reduced to uniform or perhaps even to acceptable levels, it is clearly possible to improve our knowledge of the climatic consequences of nuclear exchanges.

2. Summary Observations on the Current Appreciation of the Technical Issues

The Department of Defense recognizes the importance of improving our understanding of the technical underpinnings of the hypothesis which asserts, in its most rudimentary form, that if sufficient material, smoke, and dust are created by nuclear explosions, lofted to sufficient altitude, and were to remain at altitude for protracted periods, deleterious effects would occur with regard to the earth's climate.

We have very little confidence in the near-term ability to predict this phenomenon quantitatively, either in terms of the amount of sunlight obscured and the related temperature changes, the period of time such consequences may persist, or of the levels of nuclear attacks which might initiate such consequences. We do not know whether the long-term consequences of a nuclear war--of whatever magnitude--would be the often postulated months of subfreezing temperatures, or a considerably less severely perturbed atmosphere. Even with widely ranging and unpredictable weather, the destructiveness for human survival of the less severe climatic effects might be of a scale similar to the other horrors associated with nuclear war. As the Defense Science Board Task Force on Atmospheric Obscuration found in their interim report:

> "The uncertainties here range, in our view, all the way between the two extremes, with the possibility that there are no long-term climatic effects no more excluded by what we know now than are the scenarios that predict months of sub-freezing temperatures."

These observations are consistent with the findings in the NAS report, summarized earlier in this report. We believe the NAS report has been especially useful in highlighting the assumptions and the considerable uncertainty that dominate the calculations of atmospheric response to nuclear war. While other authors have mentioned these uncertainties, the NAS report has gone to considerable length to place them in a context which improves understanding of their impact.

We agree that considerable additional research needs to be done to understand better the effects of nuclear war on the atmosphere, and we support the IRP as a means of advancing that objective. However, we do not expect that reliable results will be rapidly forthcoming. As a consequence, we are faced with a high degree of uncertainty, which will persist for some time.

Finally, in view of the present and prospective uncertainties in these climatic predictions, we do not believe that it is possible at this time to draw competent conclusions on their biological consequences, beyond a general observation similar to that in the NAS report: if the climatic effect is severe, the impact on the surviving population and on the biosphere could be correspondingly severe.

3. Policy Implications

The issues raised by the possibility of effects of nuclear war on the atmosphere and climate only strengthen the basic imperative of U.S. national security policy--that nuclear war must be prevented. For over three decades, we have achieved this objective through deterrence and in the past 20 years we have sought to support it through arms control. Now, through the Strategic Defense Initiative, we are seeking a third path to reduce the threat of nuclear devastation.

In the remainder of this report, we will first discuss these three principal elements of our posture--deterrence, arms control, and the Strategic Defense Initiative--briefly describing each one and discussing how it relates to the issue of possible severe climatic effects. We conclude, in this regard, that these three elements, and the initiatives we are taking for each of them, remain fundamentally sound. We then explore the possibility of additional initiatives explicitly designed to mitigate climatic effects, concluding that, while some may be possible, the state of our technical understanding of these phenomena is not yet mature enough to have allowed development of specific initiatives. Finally, we review Soviet perceptions of climatic effects and their implications. We observe that Soviet perceptions are very important--indeed, that differences between their perceptions and ours would be particularly important. We conclude, however, that they have done little original work on the subject and show no evidence of regarding the whole matter as anything more than an opportunity for propaganda.

Deterrence: The evolution of U.S. strategic doctrine from the late-1940s to date is well documented. Throughout the past four decades, our policy has had to convince the Soviet leadership of the futility of aggression by ensuring that we possessed a deterrent which was sufficiently credible and capable to respond to any potential attack. Two years ago next month, the President's Commission on Strategic Forces (Scowcroft report) confirmed anew that effective deterrence requires:

- Holding at risk those military, political and economic assets which the Soviet leadership have given every indications by their actions they value most and which constitute their tools of power and control;
- Creating a stable strategic balance by eliminating unilateral Soviet advantages and evolving to increasingly survivable deterrent forces; and
- Maintaining a modern, effective strategic Triad by strengthening each of its legs and emphasizing secure and survivable command, control and communications.

These three principles are reflected in our strategic modernization program discussed below. Consistent with meeting our essential targeting requirements which derive from these three overarching deterrence principles, we also observe other policy considerations, three of which warrant special mention because they may serve to reduce concerns about climatic effects. They are a reduction of the number of weapons and total yield, rejection of targeting urban population as a way of achieving deterrence, and escalation control. Reducing unwanted damage must be an important feature of our policy, not only because of a categorical desire to limit damage that is not necessary, but also because it adds to the credibility of our response if attacked and thus strengthens deterrence. Over the past 20 years or so, this policy and other considerations have resulted in development of systems which are more discriminating. This, in turn, has led to reductions of some 30% of the total number of weapons and nearly a factor of four reduction in the total yield of our stockpile. This direction continues today, and the prospects for extremely accurate and highly effective non-nuclear systems are encouraging.

Some analyses of climatic effects of nuclear war have assumed targeting of cities. If this were regarded as an inevitable result of nuclear attack, or as U.S. policy, it would completely distort analysis of climatic effects, but more importantly, it would perpetuate a basic misperception of the nature of deterrence. Attacks designed to strike population would, by virtue of deliberately targeting heavily built up urban centers, necessarily have a high probability of starting major fires, and consequently, of creating large amounts of smoke. We believe that threatening civilian populations is neither a prudent nor a moral means of achieving deterrence, nor in light of Soviet views, is it effective. But our strategy consciously does not target population and, in fact, has provisions for reducing civilian casualties. As part of our modernization program, we are retiring older deterrent systems (e.g., the Titan missile) which might create a greater risk of climatic effect than their replacement.

A third element of our implementation of deterrence policy which bears on a mitigation of possible climatic effects is escalation control. It is our position that, however an adversary chooses to initiate nuclear conflict, we must have forces and a targeting capability so that our response would deny either motive or advantage to the aggressor in further escalating the conflict. (Of course, the prospect of our having such a capability would help deter the attack in the first place.) This objective has already in past years resulted in development of a wide range of combinations of targeting and systems selection options. While designed to strengthen deterrence and control escalation if deterrence were to fail, these options may allow us to adjust our planning so as to reduce the danger of climatic effects as our understanding of them develops.

There are those who argue, in effect, that we no longer need to maintain deterrence as assiduously as we have, because the posited prospect of catastrophic climatic effects would themselves deter Soviet leadership from attack. We strongly disagree, and believe that we cannot lower our standards for deterrence because of any such hope. As summarized above, there is large uncertainty as to the extent of those effects; certainly today we cannot be confident that the Soviets would expect such effects to occur as a result of all possible Soviet attacks that we may need to deter. This entire area of consideration--the impact of possible climatic effects on the deterrence--is made more complex by the fact that it relates to what the Soviets understand about such climatic effects and how that understanding would influence their behavior in a crisis situation. We will probably never have certainty of either; indeed, we cannot know the latter before the event, and knowing the former is made difficult by their behavior so far, which has been to mirror back to us our own technical analysis and to exploit the matter for propaganda. (Soviet handling of the "nuclear winter" issue is discussed more fully later in this report.)

The United States has, or is now taking, specific actions which relate directly to maintaining and strengthening deterrence and reducing the dangers of nuclear war: the President's Strategic Modernization Program, arms reductions initiatives, and the Strategic Defense Initiative all bear directly on effective deterrence, and are all therefore relevant to the potential destructiveness of nuclear war including possible climatic effects. We will now discuss these in turn.

Strategic Modernization Program: The President's Strategic Modernization Program is designed to maintain effective deterrence, and by doing so, is also an important measure in minimizing the risks of atmospheric or climatic effects. It is providing significantly enhanced command, control, communications and intelligence (C^3I) capabilities which, through their increased survivability and effectiveness contribute immeasurably to our ability to control escalation. Survivable C^3I contributes to escalation control and thus, as explained above, to mitigation of damage levels (of whatever kind, including possible climatic effects) by reducing pressures for immediate or expanded use of nuclear weapons out of fear that capability for future release would be lost. The improvements to our sea-based, bomber and (with the Scowcroft modifications) land-based legs of our Triad--all intended also to improve survivability and effectiveness--are also essential to maintaining deterrence.

For nonstrategic weapons, our modernization programs have also resulted in increased discrimination through improved accuracy and reduced yield. Beyond that, we have a good beginning on a program to replace some types of nuclear weapons by highly effective, advanced conventional munitions. All of this would contribute to reduction in possible climatic and other global effects of nuclear war. The possibility of such effects, of course, adds urgency to the implementation of these programs.

Arms Reductions: It is the position of this Administration that the level of nuclear weapons which exists today is unacceptably high. As a result, to the extent it is possible to reduce nuclear weapons unilaterally--particularly where both conventional and nuclear modernization programs allow replacement of existing systems on a less than one-for-one basis--we have undertaken to do so. But it would be misleading to suggest that dramatic reductions in nuclear weapons can be achieved by unilateral U.S. initiatives without increasing the risk of nuclear attack, in the absence of any indication that the Soviet Union is undertaking similar steps, or short of a changed strategic situation resulting from highly effective strategic defenses.

Major reductions in nuclear weapons can only be achieved by negotiating mutual and verifiable reduction agreements. Agreements which only legitimate the growth, or slow the rate of increase, of existing stockpiles are not in our national interest. It is for this reason that the Administration has determined that SALT II is fatally flawed. Since 1981, the Reagan Administration has demonstrated its strong desire to break with the past pattern of calling build-ups "arms control". The arms reduction proposals we have put forward have been the most extensive ones advanced by either side for over 20 years. In the area of Intermediate Range Nuclear Forces (INF), we initially proposed the elimination of all longer-range INF (LRINF) missiles--SS-20s, SS-4s, Pershing IIs, and ground-launched cruise missiles. While this remains our goal, we are prepared, as an intermediate step, to reach agreement on the reduction of U.S. and Soviet LRINF missiles. With regard to strategic weapons, we proposed reducing the number of each side's land-based and sea-based ballistic missile warheads to 5,000--a cut of approximately 33%. We have also called for equal limitations on bomber forces and restrictions on missile throw weight. As we prepare to resume negotiations with the Soviet Union in Geneva, we reaffirm our intention to seek agreements in both areas providing for significant, mutual and verifiable reductions.

As to how nuclear arms reductions bear on nuclear-induced climatic changes, the relationship is two-fold: they can strengthen deterrence--the most direct way available to us today of dealing with the possibility of severe climatic effects--and they can mitigate the effects to some extent if deterrence were to fail. However, nuclear arms reductions which may be achievable in the near term are not likely to be able to reduce significantly the consequences of a nuclear war in which a large proportion of the then existing nuclear forces would be used and in which active defenses would be non-existent or ineffective.

It is worth noting in this context, that proposals which would "freeze" development of modernized systems would also stop what has been a continuing trend in our capability--development of systems which are more discriminating and thus more restrictive in both local and global effects. We must avoid constraints that would force us to use weapons of high yield or unconfined effects.

The Strategic Defense Initiative and Arms Control: It is essential to keep potential benefits of arms reductions clearly in view when assessing what one seeks to accomplish through that process. Our objectives in arms reductions are to preserve deterrence in the near-term and begin a transition to a more stable world, with greatly reduced levels of nuclear arms and an enhanced ability to deter war based upon the increasing contribution of non-nuclear defenses against offensive nuclear arms. This period of transition could lead to the eventual elimination of all nuclear arms, both offensive and defensive. A world free of nuclear arms is an ultimate objective to which we, the Soviet Union, and all other nations can agree. The Strategic Defense Initiative research program enhances our efforts to seek verifiable reductions in offensive weapons through arms control negotiations. Such defenses would destroy nuclear weapons before they could reach their targets, thereby multiplying the gains made through negotiated reductions. Indeed, even a single-layer defense may provide a greater mitigating effect on atmospheric consequences than could result from any level of reductions likely to be accepted by the USSR in the near term.

In addition to its design objective to destroy nuclear weapons in flight, the Strategic Defense Initiative would further serve to remove any potential for environmental disaster by moving away from the concept of deterring nuclear war by threat of retaliation and, instead, moving towards deterrence by denial of an attackers political and military objective. Defenses can provide such a deterrent in two ways. First, by destroying a large percentage of Soviet ballistic missile warheads, an effective defense for the U.S. and our Allies can undermine the confidence of Soviet military planners in their ability to predict the outcome of an attack on our military forces. No rational aggressor is likely to contemplate initiating a nuclear war, even in crisis circumstances, while lacking confidence in his ability to predict success.

Second, by reducing or eliminating the utility of Soviet shorter-range ballistic missiles which threaten all of NATO Europe, defenses can have a significant impact on deterring Soviet aggression against our Allies. Soviet SS-20s and shorter-range ballistic missiles provide overlapping capabilities to target all of Europe. This capability is combined with a Soviet doctrine which stresses the use of conventionally-armed ballistic missiles to initiate rapid and wide-ranging attacks on crucial NATO military assets. By reducing or eliminating the military effectiveness of such ballistic missiles, defense systems have the potential for enhancing deterrence not only against intercontinental nuclear attack, but against nuclear and conventional attacks in Europe as well.

Some critics claim that the SDI program would cause the Soviet Union to increase numbers of weapons in an attempt to overcome the defense. This is related to the argument advanced over a decade ago that, by rendering ourselves totally vulnerable to Soviet weapons we would be able to negotiate limits on those weapons. This logic has, of course, been disproven by events; despite the fact that the U.S. made itself fully vulnerable, the U.S.S.R. increased the number of its weapons fourfold since the signing of the ABM Treaty in 1972. The guarantee that all Soviet weapons would reach their U.S. targets apparently did not give the Soviets an incentive to negotiate an equitable SALT II agreement, it encouraged them to build more weapons. Defenses would have the opposite effect; they would reduce the military and political value of ballistic missiles thereby increasing the likelihood of negotiated reductions. The prospect that powerful emerging technologies will reverse the cost leverage which offensive forces have heretofore had over defenses will further improve the likelihood of negotiated reductions.

Thus, by preventing the detonation of thousands of nuclear warheads, and, by paving the way for the elimination of those warheads by making them obsolete, the Strategic Defense Initiative may provide an answer to both the short-term and potential longer-term consequences of nuclear war.

Civil Defense: The basic goal of civil defense in the United States is to develop and maintain a humanitarian program to save lives in the event of major emergency, including a nuclear war. As to changes in our Civil Defense posture, the Federal Emergency Management Agency believe that until scientific knowledge regarding climatic impacts of nuclear conflicts is more fully developed it would be impractical to develop cost-effective policies regarding civil defense, or to change existing policies.

The particular staff elements within the Federal Emergency Management Agency responsible for civil defense planning are being kept abreast of the issues relative to possible climate effects as they develop and will be prepared to take appropriate action as soon as the relevant research now underway is complete.

As we have shown, much of our long standing policy and our current initiatives move in a direction such as to reduce the probability of severe climatic effects even though they were instituted before such effects were under investigation. Specifically, we are maintaining a strong deterrence augmented by necessary force modernization and verifiable, mutual arms reductions. We are continuing the development of accurate, discriminating systems designed to achieve their military objectives with the least nuclear yield possible. We have implemented and are constantly refining options for escalation control. We have, long ago, rejected the targeting of population as a means of securing deterrence. Finally, we have begun the Strategic Defense Initiative which has as its ultimate goal the obsolescence of nuclear weapons. All these things work first to deter nuclear war--the best way of avoiding the effects at issue--and second, to reduce these effects were deterrence to fail.

Possible Further Initiatives: As we have already pointed out, reducing unwanted damage must be an important feature of our policy. It would be entirely consistent with our policy and recent practices to continue to make weapons more discriminating, to reduce their yields by improved accuracy where possible, and in other ways to minimize effects not directly related to target damage, so as to both enhance the credibility of our deterrent and to reduce unwanted destruction, including the potential for ameliorating possible climatic and other environmental effects. In fact, we are pursuing such objectives in general, though programs are in various stages of development.

Beyond these continuing trends, with regard to targeting and the detailed characteristics of the nuclear forces, which pertain both to deterrence and to limiting damage, as our understanding of climate effects improves it is prudent to develop other measures intended to reduce those effects if deterrence were to fail. Besides possibly adding targeting options to those which already exist to limit damage, some technical developments might also contribute. For example, highly accurate, maneuverable reentry vehicles and earth penetrating weapons, both of which might be useful in strengthening deterrence, could reduce yields and in other ways limit the starting of fires. In the farther future, for selected missions, nonnuclear systems, if feasible, might replace some strategic nuclear systems, as we have begun to do for non-strategic systems.

Today, however, we have inadequate knowledge to evaluate possible measures. As the analytical methods for assessing climatic effects become more accurate and we gain confidence, they can be used to predict what kind of changes will in fact reduce the dangers of nuclear war. For example, some have suggested that reducing the height of burst of the nuclear explosions could reduce the area of thermal effect and, therefore, the amount of material burnt. However, at lower heights of burst, increased fallout might be worse than any mitigation of long-term change in the climate. Where such trade-offs are involved, we need better information before deciding.

4. Soviet Activities on Climatic Effects

Soviet science spokesmen and media have claimed that Soviet scientists had independently confirmed the probability of severe long-term atmospheric effects as a consequence of nuclear exchange. Initially, their claim was accepted in the West; however, an examination of open Soviet publications specifically discussing this prediction shows their claim to be unfounded.

In their writings on the "nuclear winter" hypothesis, Soviet scientists have neither used independent scenarios nor provided independent values of the essential parameters characterizing the key ingredients (soot, ash, and dust) on which the hypothesis principally depends. Instead, Soviet researchers--and on this subject, it is hard to tell the difference between scientific workers and propagandists--have uncritically used only the worst-case scenarios and estimates from other work. They have taken these estimates and merely adapted them to borrowed mathematical simulations of state-of-the-art multi-dimensional models of global atmospheric circulation modified to instantaneously simulate long-term global effects after an exchange. For example, the primary atmospheric circulation model used by the Soviets in the case of the widely publicized study by Soviet researchers V. Aleksandrov and G. Stenchikov, is based on a borrowed, obsolete, U.S. model. Thus, given the sources of inputs and methods for their "studies," their findings do not represent independent verifications of the hypothesis.

Further, Soviet reports tend to stretch the conclusions well beyond what even their uncritical, worst-case assessments support, embellishing statements of technical analyses with conclusions that any use of nuclear weapons at all will lead to the disappearance of the human race or similar propagandistic statements the Soviet Union has made on and off for years, even before these atmospheric phenomena surfaced.

The Soviet scientists have contributed very little to the international study or understanding of this phenomenon. This shortfall has not gone unnoticed by other non-Soviet scientists, some of whom have characterized their analyses as "crude" and "flawed." Time after time their presentations contain exaggerated claims, which are criticized by their foreign colleagues following the formal briefing, but subsequent presentations do not reflect any change, even though in private the Soviets acknowledge the exaggeration.

This is not to say that, over the years, the Soviets have not published studies that have examined various effects and phenomena (dust, fires, soot, etc.) of nuclear detonations; they have. However, the Soviets have made little use of such findings in their public discussions and models of the phenomenology associated with the current climate effects hypothesis. They have not been forthcoming in providing information that might have been of use with regard to reducing the uncertainties associated with the assumptions made in their work. Repeatedly, they ignored an American request for information derived from Soviet pre-1963 nuclear tests and large-scale fires. The flow of useful technical work has been almost all one-way. It is worth noting that Soviet interest in this topic provides them with some degree of additional access to U.S. scientists (and their technology) who are involved with super-computers, software model development, and global and mesoscale climate phenomenology.

If the Soviets see this issue as a matter that might substantially affect their policies, strategy, or force structure, those views have so far been hidden from us. It is important that, whatever the outcome of the scientific work regarding climatic effects of nuclear war, the understanding should be commonly held by all of the nuclear powers and help to reduce the risk of nuclear destruction. Unfortunately, recent Soviet performance and statements on the subject do not appear supportive of establishing a truly common understanding, either on the phenomena themselves or on their implications for the strategic relationship between the two powers. If the Soviet leadership does believe that the possibility of severe climatic effects is important, then this issue will add its weight, along with the many other imperatives which the United States and the people of the world feel so strongly, to produce a truly constructive approach toward a world in which the fears aroused by such horrors as nuclear war or the so-called "nuclear winter" will be a thing of the past.

REPORT TO THE OFFICE OF SCIENCE
TECHNOLOGY AND POLICY

INTERAGENCY RESEARCH REPORT FOR ASSESSING CLIMATIC EFFECTS OF NUCLEAR WAR

Prepared by the National Climate Program Office, NOAA

February 5, 1985

PREFACE

Presidential Science Advisor Dr. George Keyworth II requested that the National Climate Program Office, NOAA, develop an interagency research plan which addresses the climatic effects of nuclear war. The research plan was prepared by a panel of federal and university scientists convened by the National Climate Program Office (Committee B). The plan identifies priorities for a coordinated interagency program designed to reduce the uncertainties in the various parameters of climatic conditions after a nuclear exchange. The plan was approved by an interagency review committee (Committee A) for submission to the Office of Science and Technology Policy (OSTP). Membership of committees A and B are given in Appendix A. Copies of this plan are available from the Executive Office of the President, Office of Science and Technology Policy, Washington, D.C. 20506.

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Appendix A - National Research Plan Committees

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EXECUTIVE SUMMARY

1. The purpose of this document is to present a research plan that addresses the need for a rapid improvement in understanding and for reducing important uncertainties in the "nuclear winter" hypothesis. The plan lays out the basic strategy for a coordinated interagency program.

2. Recent modeling studies of the likelihood of extensive fires following multiple nuclear explosions have suggested that a prolonged period of subfreezing surface land temperatures might occur following a limited or full scale nuclear war. The basic hypothesis of a "nuclear winter" is that the smoke and dust produced during nuclear fires and explosions, once it is lofted high in the atmosphere, would block much of the sunlight reaching the earth's surface. Of these two types of particles, the smoke is thought to have a greater effect on climate because it absorbs sunlight.

3. However, these studies, like any modeling exercise, are strongly dependent on source inputs, model assumptions, and representative target data bases. Because of the uncertainties in source inputs and the present level of sophistication in models, the hypothesis of a nuclear winter cannot be accepted or rejected at this time.

4. Source inputs for the smoke component depend on the character of fires (size, intensity, distribution, combustibles), which determine the amount of particulate matter produced and its optical properties, and local meteorological condition. Source inputs for the dust component are thought to be better understood and depend on the excavation of surface material by ground bursts.

5. Air heated by an extended fire rises convectively carrying with it smoke and other entrained material such as ash and dust. Just where this particulate material is carried depends on the area of the fire and its intensity, the turbulence in the flow and the entrainment of unheated air, the conditions of temperature and humidity in the ambient atmosphere, and the local wind fields. In general, the larger and more intense the fire, the higher the plume (and smoke) will rise. The higher in the troposphere the smoke is injected, the more persistent it will be and the more effect it is expected to have on surface temperatures. Very intense fires, firestorms, may even inject material into the stratosphere.

6. Microphysical and plume-cloud interactions on scales up to 100 km strongly determine the height of smoke plume injection and early rainout. Mesoscale processes on scales of 10 to 1000 km strongly determine mixing and smoke removal. There are large uncertainties in understanding atmospheric processes on the micro, plume-cloud, and mesoscales.

7. Events in the first hours and days following a nuclear exchange are crucial in determining the composition and amount of source input, the height of dust and smoke injection into the atmosphere, and the initial degree of scavenging and rainout of smoke.

8. Climate models provide the only means to simulate global-scale atmospheric effects of nuclear war. While these models are sophisticated and

are capable of successfully simulating many aspects of the observed weather and climate, including the seasonal cycle, there are many aspects of these models that have not been designed to adequately represent the climatic effects of very large smoke injections. The interactive effect of large amounts of smoke must be considered in existing climate models for results to be more realistic.

9. The determination of a representative target data base which includes expected yield, location and types of targets, sequencing, types of explosions, etc. will greatly affect the result of model studies. A plausible target data base is needed for estimating the resultant climatic effect.

10. The priorities of the research program are to address the major uncertainties in source inputs, improve modeling of atmospheric effects of nuclear war, and provide a plausible set of climatic conditions for assessing consequences. Not all uncertainties of source inputs and climatic effect can be reduced, but it is possible to considerably improve knowledge of the climatic consequences of nuclear war and thus put decision-making at all levels on a firmer scientific basis.

11. Various research strategies are proposed which include: Theoretical studies and laboratory experiments, field experiments, diagnostic studies, modeling and assessment studies.

12. Theoretical studies of the detailed chemistry and physics of the combustion process with the fluid mechanics and energy transfer factors under which they occur can help in the design of relevant laboratory experiments and also extend their results.

13. Laboratory experiments will help in determining the amount of smoke formed in initial fires, the aerosol yield from mixed fuels, the chemical composition of the smoke, particle sizes and optical properties of smoke, coagulation potential of mixed fuel sources, and dynamics of mixed fuel source-smoke interactions.

14. Field experiments involving managed fires, primarily of vegetation, are planned for routine and special burns to study the initial height reached by the smoke and its early removal and spreading under different environmental conditions.

15. Satellites can rapidly identify large fires and provide data which will be useful in studying the spread of smoke plumes from extensive forest fires, their heights of injection, and optical priorities. A limited rapid fire-response program can be planned to sample fuel loading, atmospheric conditions, particulate and chemical effluent, and to assess the atmospheric interactions that follow from fires of opportunity.

16. The degree to which the results of laboratory and field fire experiments can be extrapolated to large-scale urban and vegetative fires is unknown. Proposed scaling experiments are crucial first steps in addressing this uncertainty.

17. Diagnostic studies of both historical and contemporary data may yield insight into the effects of dust and smoke based on analogues of previous

large fires. Tropical burning and desert dust storms represent the best large-scale analogues of the nuclear winter.

18. Modeling studies involving present cloud, mesoscale, and global circulation models will be made in order to improve our knowledge of the lifetime of the particles in the atmosphere, the rapidity and scale of their dispersal, and the resultant changes in climate. Emphasis will be placed on interactive processes between the particles and other elements of the climate system.

19. Although much of the debris from a nuclear war will be injected into the troposphere, substantial dust and possibly soot may be ejected into the stratosphere. Global models devoted to stratospheric dynamics will be needed to properly evaluate the effect of stratospheric debris.

20. The minimum results of this plan should be (1) improved estimates of fuel loading in urban and nonurban environments; (2) reduction in the range of estimates of smoke emissions and interactions in the atmosphere; (3) determination of physical and optical properties of smoke for fires of different sizes, intensities, and composition; (4) direct measurements of radiative effects for a variety of smoke and dust conditions; (5) improved simulation of climate effects using models which include interactive smoke spreading and scavenging, diurnal and seasonal cycles, and improved parameterizations; (6) narrower ranges of possible climate impacts; (7) determination of yield-atmospheric loading relationships for policy consideration, such as threshold levels for significant climate changes; and (8) preliminary assessment of environmental issues other than smoke and dust.

21. Major advances are needed in the overall state of global modeling before the atmospheric processes leading to a "nuclear winter" can be reasonably assessed. These include the effects of the atmosphere on the "cloud" in the very early stages as well as in the longer term, the effect of the "cloud" on the atmosphere, the interaction between the different scales of activities, and the response of the atmosphere to abnormal conditions never before experienced. This plan proposes to make an initial effort to address these areas for improving global modeling.

22. Evaluating the first order climatic consequences of nuclear war is extremely complex and requires the expertise of many disciplines. A carefully planned coordinated research effort is required to develop a more realistic picture of possible environmental consequences. The "nuclear winter" problem, however, is embedded in more general problems of understanding fire phenomenology, atmospheric chemistry and physics, mesoscale and global circulation, and cloud dynamics.

1. OVERALL STRATEGY

Problem

The hypothesis underlying a "nuclear winter" is that dust raised by surface bursts and smoke produced by thousands of fires initiated by a moderate or large-scale nuclear exchange would spread over much of the globe and cause the average surface land temperatures to drop sharply (even to below freezing) for up to several months. Preliminary scientific estimates of the effects are, however, based on many assumptions and uncertainties. These include nuclear war scenarios, estimates of how much smoke is produced during fires, how much dust is raised by explosions, how high smoke and dust are injected into the atmosphere, how much of the material is retained in the atmosphere and for how long, how the smoke and dust interact with and are distributed in the atmosphere, and how this material alters the radiation balance and general circulation of the atmosphere. Estimates of the plausible ranges of uncertainties for these parameters are given in Appendix B.

The objective of this interagency plan is to present a research program that addresses the need for a rapid improvement in understanding and reducing important uncertainties in the "nuclear winter" hypothesis. Time and resources do not permit this plan to be a comprehensive review or assessment; rather, the plan lays out a basic strategy for a coordinated interagency program. The program includes many parts which together form an "ideal" research agenda. It is a carefully crafted program that builds and enhances existing knowledge. It provides for exploratory review of issues other than smoke and dust that exist in published reports to determine whether any of these require a major assessment. These studies are crucial for anticipating other nuclear effects issues.

Proposed Program

While new observational, theoretical, and modeling studies in atmospheric chemistry, cloud physics, and mesoscale and global circulation will contribute to the goals of the plan, major reductions in present uncertainties require both better data on source inputs and better representation of atmospheric effects. Inventories of possible fuel sources in urban and nonurban areas are now being collected and provide a statistical basis for estimating potential smoke emissions. Laboratory and field studies are required, however, to quantitatively describe the physical characteristics of smoke emissions and their potential longevity in the atmosphere. While the problem of evaluating the climatic consequences of nuclear war is somewhat dependent on the types and locations of nuclear explosions, we are still greatly hampered by an insufficient modeling capability needed to disperse and distribute smoke and to extrapolate to the types of fires which might be produced.

It is the recommendation of the drafting committee (Committee B) for the research plan that highest priority be given to (1) implementation of a suite of carefully planned laboratory and field fire experiments and (2) modeling studies to better describe the properties of potential source inputs to the atmosphere and their subsequent radiative, cloud, and chemical interactions.

Laboratory experiments on urban and vegetative material can provide valuable information on smoke characteristics, coagulation, and optical properties. Such experiments must be jointly planned by experimenters and theoreticians. A number of large-scale prescribed fires are purposely set each year by forest managers, and these will provide opportunities for field studies. In addition, a fire rapid-response program can be organized to study anticipated fires of opportunity.

Besides experimental studies of individual fires, there are regional-scale natural phenomena which have some characteristics of the aerosols input of a "nuclear winter." The best-known analogues are the burning of tropical forests (in slash-and-burn farming) and dust storms. By measuring the amount of soot which is naturally injected in the atmosphere and the steady state loading of the atmosphere in the tropics, insight may be gained into the processes that remove soot from the atmosphere. Saharan dust storms are optically dense enough to cause surface temperatures to drop many degrees for short periods. Studies of these events may better reveal how the thermal structure of the atmosphere changes when aerosol clouds are present and how aerosols are transported and removed from the atmosphere. These natural analogues provide our only experimental tests of the large-scale dynamical response of the atmosphere to heavy loading.

Global models provide the only means of simulating global scale effects of nuclear war. These models are crucial for decision making at all levels. Thus, concurrent with the above laboratory and field efforts, an accelerated and well-organized national effort is needed to improve atmospheric modeling from small to large scales, including the important interactions among various scales. A series of model improvements in physical representations and parameterizations can now be implemented in existing atmospheric models to provide a more realistic assessment of climatic consequences. New observational data derived from the fire experiments will be useful in validating the smaller scale models and in providing input to all of the modeling experiments.

These combined efforts on theory, experiment, observation, and modeling, linked together, can provide maximum scientific leverage to reduce major uncertainties in understanding the atmospheric consequences of nuclear war. Evaluating the first-order climatic consequences of nuclear war is extremely complex and requires the expertise of many disciplines. There are no quick experiments or model simulations that will adequately estimate the outcome. Rather, a carefully planned coordinated research effort is required to develop a more realistic picture of environmental consequences. Not all uncertainties can be eliminated, but a better knowledge of the range of possibilities can be obtained.

Program Implementation

While DOD and DOE have research efforts underway at present, any interagency plan should draw upon contributions from other federal agencies and university scientists who have expertise, equipment, and experience applicable to the problem of the climatic consequences of nuclear war. This effort will coordinate national resources for theoretical and field experiments and modeling studies considering the availability of total funds, thus maximizing the entire research and development effort.

Summary

It is possible to improve considerably knowledge of the climatic consequences of nuclear war. Expertise, equipment, and scientific commitment are available to accomplish this. The problem, however, requires strong interagency coordination to ensure a balanced and cost-effective program. The plan proposes an effort focused on theoretical studies, laboratory and field experiments, and modeling studies. The experiments are aimed at reducing the largest uncertainties in the "nuclear winter" hypothesis. Concurrent development of representative target data bases will be used for input into the theoretical modeling studies. The results of these studies should be unclassified and available to the scientific community through standard scientific journals and technical reports.

2. BRIEF REVIEW OF RECENT STUDIES

The concept of a "nuclear winter" is based on the proposition that large-scale fires and excavated debris produced by many nuclear explosions would create a hemispheric to global blanket of smoke and dust sufficient to greatly reduce the amount of sunlight reaching the earth's surface. A prolonged period of sharply reduced land surface temperatures would follow for much of the northern hemisphere, and perhaps the world. The relevance of dust to this hypothesis is based on studies related to dust storms on Mars and the extinction of the dinosaur, some 60 million years ago. L. Alvarez et al. (1980) postulated that an asteroid hitting the earth put so much dust into the atmosphere that sunlight and photosynthesis were significantly reduced long enough to lead to extinctions for large species. The Alvarez hypothesis stimulated researchers and others to calculate the possible climatic effect of such a massive dust cloud, and the National Academy of Sciences to reassess the effects of dust on climate.

Crutzen and Birks (1982) were the first to attempt to quantify the possible input of smoke into the atmosphere from burning forests following a nuclear war. They concluded that for periods of several weeks or longer, such fires would produce sufficient smoke to reduce incoming solar radiation over wide areas of the earth's surface to below that required for photosynthesis. They conclude that:

> "As a result of a nuclear war, vast areas of forests will go up in smoke - corresponding at least to the combined land mass of Denmark, Norway and Sweden. In addition to the tremendous fires that will burn for weeks in cities and industrial centers, fires will also rage across croplands and it is likely that at least 1.5 billion tons of stored fossil fuels (mostly oil and gas) will be destroyed. The fires will produce a thick smoke layer that will drastically reduce the amount of sunlight reaching the earth's surface. This darkness would persist for many weeks, rendering any agricultural activity in the Northern Hemisphere virtually impossible if the war takes place during the growing season."

A subsequent study by Crutzen, Galbally, and Bruehl (1984) using a simple rainout procedure, aerosol physics, and radiative equilibrium models reaffirms their basic conclusion. But their analysis is "based on very few and uncertain data from simple laboratory tests, the results of which were extrapolated to mass fires. The numerical results of this study should, therefore, not be taken too exactly."

The first major studies of the climate and biological consequences of nuclear war from both dust and smoke were published by Turco, Toon, Ackerman, Pollack and Sagan (known as TTAPS) and Paul Ehrlich et al. in Science in 1983. The TTAPS report coined the term "nuclear winter" and said that

> "For many simulated exchanges of several thousand megatons, in which dust and smoke are generated and encircle the earth within 1 to 2 weeks, average light levels can be reduced to a few percent of ambient and land temperatures can reach - 15° to -25°C. The yield threshhold for major optical and climatic consequences may be very low: only

> about 100 megatons detonated over major urban centers can create average hemispheric smoke optical depths greater than 2 for weeks and, even in summer, subfreezing land temperatures for months. In a 5000-megaton war, at northern mid-latitude sites remote from targets, radioactive fallout on time scales of days to weeks can lead to chronic mean doses of up to 50 rads from external whole-body gamma-ray exposure, with a likely equal or greater internal dose from biologically active radionuclides. Large horizontal and vertical temperature gradients caused by absorption of sunlight in smoke and dust clouds may greatly accelerate transport of particles and radioactivity from the northern hemisphere to the southern hemisphere. When combined with the prompt destruction from nuclear blast fires, and fallout and the later enhancement of solar ultraviolet radiation due to ozone depletion, long-term exposure to cold, dark, and radioactivity could pose a serious threat to human survivors and to other species."

Paul Ehrlich and 19 co-authors analyzed the consequences of many months of subfreezing temperatures, low light levels, and high doses of ionizing and ultraviolet radiation on global biological systems. They conclude that survivors of a nuclear war would face starvation as well as

> "freezing conditions in the dark and exposure to near-lethal doses of radiation. If as now seems possible the southern hemisphere were affected also, global disruption of the biosphere could ensue. In any event, there would be severe consequences, even in the areas not affected directly, because of the interdependence of the world economy. In either case the extinction of a large fraction of the earth's animals, plants, and microorganisms seems possible. The population size of Homo sapiens conceivably could be reduced to prehistoric levels or below, and extinction of the human species itself cannot be excluded."

"Nuclear winter" is a new dimension of the possible consequences of nuclear explosions. A 1975 report of the U.S. National Academy of Sciences did not consider the climatic effects of nuclear war significant. The main concern of the report was potential damage to ozone in the stratosphere. From comparison with volcanic eruptions, the report concluded that "stratospheric dust injection from a 10,000 megaton nuclear exchange would be comparable with that from a large volcanic explosion such as that of Krakatoa in 1883 and therefore might have similar climatic impact. At most, a 0.5°C deviation from the average lasting for a few years might be expected." No input from large-scale fires was recognized in this report. An earlier Academy report did identify the possibility of lingering fires in a post-nuclear world, although with uncertain ecological consequences (NAS, 1968).

The climatic consequences of nuclear explosions have been analyzed by two major dynamical modeling groups and others in the United States and by the Computing Center of the USSR Academy of Sciences. Results from the Lawrence Livermore National Laboratory (LLL) two-dimensional atmospheric circulation model were presented at the Third International Conference on Nuclear War in

Erice, Sicily (1983). MacCracken, using the LLL model with a 10° latitude resolution and 9 layers in the vertical atmosphere, extending up to 35 km, showed that the cooling averaged over all northern hemisphere land surfaces will be 10-15°C within a few days of the smoke injection.

Analysis by Covey, Schneider and Thompson (1984) with the NCAR community climate model, a three-dimensional general circulation model using 4.5° latitude and 7.5° longitude resolution with 9 vertical layers, shows substantial surface cooling for tropospheric aerosols of absorption optical depth 3 injected in the northern hemisphere midlatitudes and maintained for 3 weeks. They conclude that:

> "Mid-latitude surface temperatures in continental interiors can drop well below freezing in a matter of days regardless of season. Our results, although based on several assumptions, suggest that circulation changes caused by aerosol-induced atmospheric radiative heating could spread the aerosols well beyond the altitude and latitude zones in which the smoke was initially generated."

The model employed at the Computing Center of the USSR Academy of Sciences is an extension of the Mintz-Arakawa model of the Global Circulation (Gates et al, 1971) with horizontal resolution of 12° latitude by 15° longitude and two vertical layers representing the troposphere from the surface to about 12 kilometers. The aerosol distribution in the Soviet model is based on the TTAPS 10,000 megaton war scenario with smoke of average optical depth 3.5 distributed between 12° and 90°N latitude. Initial results show a temperature decline of as much as 25°C over large continental areas beneath the smoke cloud (Aleksandrov and Stenchikov, 1983).

A comparison of modeling results between the NCAR general circulation model and the climate model at the Computing Center of the USSR Academy of Sciences has been prepared by S.L. Thompson, et al. (1984). Both models produce subfreezing land surface temperatures under a dense northern hemisphere smoke cloud, particularly in continental interiors.

Robock (1984) has recently suggested, on the basis of a seasonal energy balance climate model, that the climatic effects of a nuclear war might persist for several years because of feedbacks in the climate system due to snow/albedo and sea-ice/thermal inertia changes. These feedbacks become important in the years following a nuclear exchange when the initial dust and smoke perturbation has been reduced.

Calculations of climatic effects by different models have given similar results when the same essential assumptions are made. These include uniform injection of 200 to 300 teragrams of black smoke into the troposphere of the northern hemisphere. However, key assumptions of amount, injection altitude, optical properties of smoke, and early removal or scavenging processes have not been independently determined. None of the calculations published to date have been interactive in the sense of calculating the spread of smoke, its effects on the weather, and the subsequent effects on the scavenging of the injected materials.

S.F. Singer, S.L. Thompson, S. Schneider, and Covey exchanged views on the possible extent of a nuclear winter in Nature (1984). They identified many of the uncertainties associated with estimating source material from nuclear explosions and fires and the limitations of current modeling. Singer is not alone in expressing skepticism about some of the seemingly extreme "nuclear winter" effects (Teller, 1984).

Policy implications of "nuclear winter" effects have been argued by Sagan (1984), and more general nontechnical reviews of a "nuclear winter" have been published by P. Ehrlich (1984) and A. Ehrlich (1984). A history of such studies leading up to 1984 is given by Schneider and Londer (1984). An extensive discussion of both the atmospheric and the biological consequences of nuclear war, with emphasis on "nuclear winter," is given in the recent book by Ehrlich et al., 1984. A renewed assessment of climatic effects of nuclear war has been completed by the NAS (1984). The Academy concludes that despite large uncertainties in source inputs and modeling, there is reason to expect widespread climatic affects due to extensive fires caused by nuclear exchange.

Many of the statements and conclusions cited above are being debated in the scientific community. Many uncertainties exist in the underlying assumptions and in available data bases. The interagency research plan presented here is designed to address these basic scientific issues and uncertainties.

3. REDUCING UNCERTAINTIES IN GENERATION AND EVOLUTION OF SOURCE MATERIAL

The major uncertainties in evaluating the climatic effects of a nuclear exchange relate to estimates of the amounts, altitudes of injection, and properties of dust and the smoke generated in large-scale urban and vegetative fires, and their subsequent interaction with the atmosphere. Atmospheric processes and factors involved are shown in figure 1 and summarized in table 1. The discussion that follows reviews these uncertainties and identifies measurements required to resolve them. The main conclusion is that many of these crucial questions can be treated in both laboratory and field experiments.

Smoke Emission

Many factors determine the amount of material burned in a fire. These include fuel type and distribution, the distribution of ignition points, the fire spread, and the fraction of available fuel which actually burns. The fraction of burned material which is converted to particulate matter, in turn, depends on these and other factors, including the oxygen environment in which the principal combustion takes place, the residence time of soot particles within the flame (burnout), and the thermal environment in which soot formation takes place. Substances that have significant innate oxygen in their composition (such as the cellulose in wood, phytomass, and some fabrics) burn somewhat cleaner, all other things being equal, than substances which are less well oxygenated. Some substances not well oxygenated can also burn rather efficiently and produce little smoke by virtue of the volatile and combustible nature of their pyrolytic emissions. By contrast, some materials (some plastics and wood lignins) have copious soot emissions when they burn. Thus the structure of the fuel molecules determines, in part, the emission of smoke.

The availability of oxygen in the early stages of fires is important in determining smoke yields. In enclosed fires, for example, the ratio of available to required oxygen levels needed for complete combustion can become quite small. There are two reasons for this: First, the oxygen supply must come through the available apertures (windows, doors, leaky seams). The resultant inefficient combustion causes the release of unburned hydrocarbons which condense to form smoke. Second, additional smoke and soot are generated by the acceleration of pyrolysis and incomplete combustion because of the elevated temperatures reached in enclosed areas. Conditions similar to an enclosed fire's increased smoke emissions might occur in the centers of large mass fires due to the inability of oxygen to penetrate effectively.

On the other hand, burnout of volatiles and carbonaceous residue, leading to a clean-burning fire, may take place, depending on the size of the burning area and on the intensity of the fires. For moderately low-intensity, individual fires, particle mass and character will be determined primarily by material type and ventilation effects. For larger and more intense fires with adequate ventilation from below, continued combustion may extend to considerable heights, allowing for a much more efficient burn.

There have been many laboratory and observational studies of smoke generation from various fuels. Some of these measurements also include

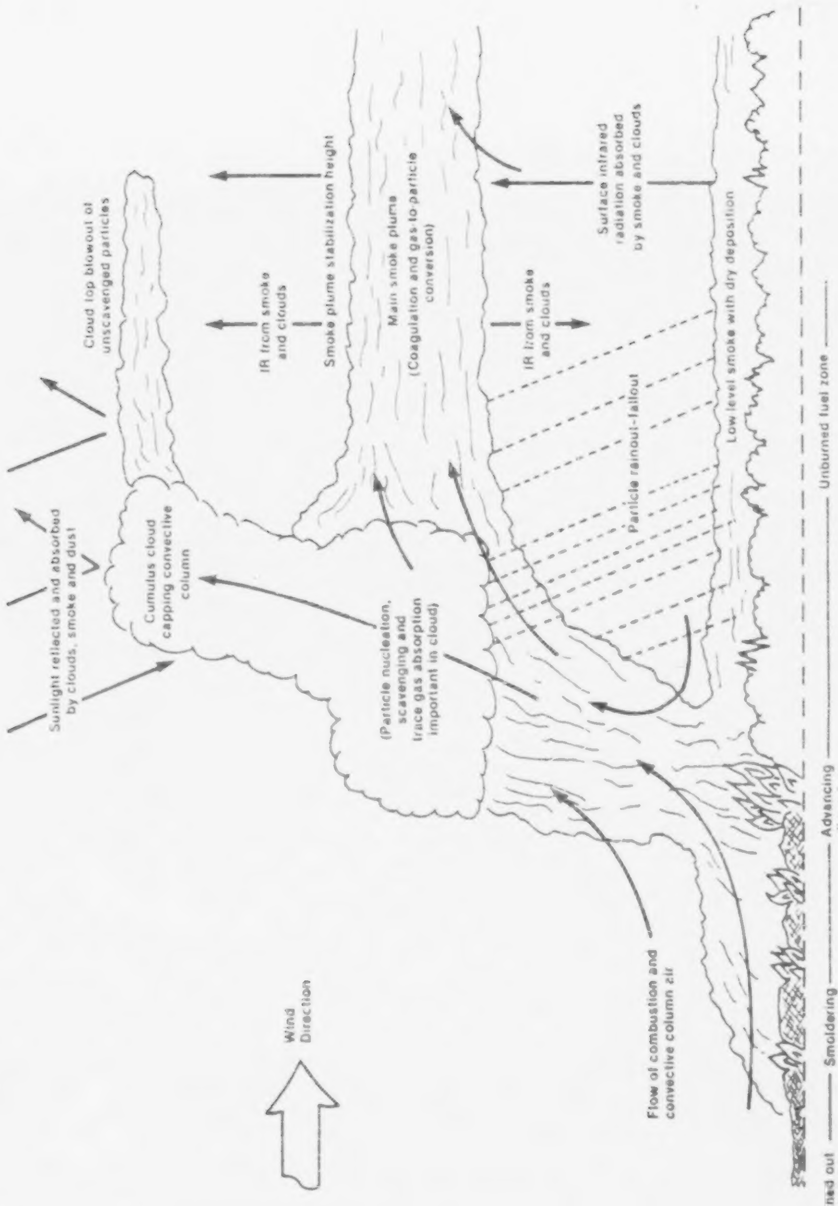
Sunlight reflected and absorbed by clouds, smoke and dust
Cloud top blowout of unscavenged particles
Cumulus cloud capping convective column
IR from smoke and clouds
Smoke plume stabilization height
Wind Direction
(Particle nucleation, scavenging and trace gas absorption important in cloud)
Main smoke plume (Coagulation and gas-to-particle conversion)
IR from smoke and clouds
Surface infrared radiation absorbed by smoke and clouds
Flow of combustion and convective column air
Particle rainout-fallout
Low level smoke with dry deposition
Burned out ignition zone
Smoldering fire
Advancing fire edge
Unburned fuel zone

Figure 1: Schematic representation of major components of forest fires relevant to "nuclear winter" studies.[14]

Table 1. Atmospheric Processes Important to Investigating Effects of Large-Scale Fires

Component	Questions Addressed	Measurements
Source Material	Amount of smoke and soot produced for a variety of fire sizes, intensities, and fuels	o Ignition point fuel type and distribution o Fire intensity o Oxygen environment o Ventilation o Thermal environment
Properties of Smoke	Level of infrared and visible extinction	o Composition of smoke o Smoke optical properties o Smoke mass and size distribution o Scattering phase function o Particle shape o Infrared and solar optical depths
Plume Dynamics	Height of plume; Entrainment processes	o Plume top and bottom o Ambient humidity, winds, and temperature o Vertical stability o Altitude of formation of water clouds o Plume velocities
Cloud Interactions and Removal Processes	Extent to which smoke and clouds interact; Degree of scavenging; Rates of precipitation; Degree of coagulation	o Smoke size before and after passing through clouds and precipitation o Density and size distribution of particles o Optical properties of soot o Electric charge on cloud and precipitation particles o Cloud drop distribution o Cloud condensation nuclei in fresh and old smoke o Ice nuclei

Table 1 (continued)

Smoke Cloud Dynamic Interactions	Consequent radiative effects and circulation; Efficiency of clouds in entraining air and dust; Levels in atmosphere where cloud would occur	o Carbon soot size and amount o Levels of turbulence over fires o Direct measure of visibility and attenuation o Backscattering coefficient

assessments of the effects of flaming versus smoldering conditions. Other experiments have addressed some of the effects of oxygen-deficient combustion environments. Specific studies needed for evaluating the nuclear scenarios are inventory of fuel beds, particularly in urban areas (see, for example, Larson and Small, 1982) and theoretical assessments of smoke generation from mixed fuel fires, the relation of smoke emission from small-scale tests to room-sized and larger fires, oxygen availability (which depends in turn on oxygenation level of modern urban materials, confined fire effects, blast enhancement of open fires, effects of asphalt and rubberized fuels, and ventilation effects in large fires), and the thermal environment and burnout in large-scale intense fires. These subjects are generally new areas in large-scale fire research although they conveniently build on existing programs and facilities.

The occurrence of firestorms during nuclear exchanges could lead to a significant enhancement of materials in the stratosphere. Appendix B notes that the range of fire particles propelled by firestorms into the stratosphere may be between 0 to 20% of the amount ejected into the atmosphere. However, the conditions under which firestorms occur are not fully understood. Efforts will be made to investigate the formation and effects of firestorms through modeling and controlled experiments, if appropriate.

Optical and Other Properties

The optical properties of smoke particles are critical to calculations of the climatic changes following a nuclear exchange since they determine the amount of sunlight and infrared radiation absorbed and scattered by the particles.

Some measurements have been made of the properties of smoke particles created in laboratory environments and in natural fires. For example, studies have been done on the optical absorption of soot produced by laboratory burning of pine needles. Others have measured the particle sizes and mass emission rates in a variety of small, prescribed fires in Washington and Oregon. Although such studies have limited the uncertainty attached to some properties of smoke, a number of significant questions remain.

Optical properties of smoke are sensitive to the fuel composition, fire temperature, fire ventilation, and degree of coagulation in the plume. Measurements have not been made in urban fires, where many synthetics are present, or in very large forest fires. High smoke loadings in a large fire may lead to rapid coagulation and growth into large particles with small optical cross-sections. On the other hand, coagulation may not be significant or it may lead to differently shaped particles with different results. The scattering and absorption properties of aerosols are determined by their chemical composition, the particle size distribution, and to a degree, by particle shape. There are large differences between theoretical and observed properties of particles in plumes. Sufficient radiation measurements using state-of-the-art instruments have not been made.

Theoretical calculations predict that a water cloud containing even small amounts of soot can effectively absorb sunlight. The heating might act to dissipate many clouds before they are able to precipitate or before they could enhance convection, precipitation, and soot removal.

In order to resolve these questions, the composition of the smoke and the smoke optical properties need to be determined for fires of different sizes, intensities, fuel compositions, and weather conditions. Direct data on the particle scattering phase function, on the optical depth for all wavelengths of the resultant cloud, and on the solar heating rates will improve our ability to calculate the radiative parameters of a dense smoke cloud of the type which may follow a large nuclear exchange.

The mass and size distribution of smoke particles in plumes must be determined in order to resolve the significance of coagulation and particle size and to better relate the super micron smoke mass to the mass of burned material. In this regard, it should be noted that recent measurements of smoke particle size distribution from forest fires have shown that the supermicrometer particle mass in the range of 1-50 micrometers is comparable to the submicrometer mass. Large fires can be expected to produce millimeter-sized ash and debris in significant concentrations. This is important because these are often irregular, low-density particles with substantial residence times. If they become coated with water in a cloud, these particles are large enough to initiate coalescence and are subject to scavenging by rain.

A major factor in removal processes is the nucleation character of the particles or the coagulation of radiatively active particles such as elemental carbon particles with hygroscopic aerosol particles. These properties may be quite different for urban and rural fires. If a substantial amount of the material has either water or ice nucleation characteristics, it may contribute to its own washout, or conversely, to colloidal stabilization and reduced washout.

Because many particle characteristics depend strongly upon the fuel source and fire environment, studies of forest fires will not resolve questions about the optical properties of smoke from urban fires. It will be necessary to extrapolate laboratory data, or data from small burns of urban materials. A well-planned series of scaling experiments will be needed. Accompanying these must be a correlated development of the capability to predict the generation of particulates and condensible vapors from solid fuels and their evolution as a function of fire and atmospheric conditions.

Plume and Cloud Dynamics

The fraction of smoke that remains in the atmosphere and the rate of dispersion depend on interacting processes occurring on several scales. Plume and cloud-scale interactions on the order of 1 to 100 km are crucial in several ways. The dynamics of plume rise and turbulent entrainment are important in the quenching of combustion, condensation of unburned pyrolysis products on smoke particles, and specification of the environment in which mature smoke particles grow through coagulation. Dynamics, especially wind shear and entrainment, along with atmospheric stratification, moisture profile, and fire intensity and extent, serve to define the plume stabilization height, which gives the maximum smoke injection altitude. This is a very important input in meso and large-scale models.

Numerous tested models for plume rise are available from such sources as volcanoes, smokestacks, and cooling towers. However, these models are not easily extended to urban or wild fires because of differences in sources, time and space scales, and injection products. In particular, the effects of atmospheric stability and convection, entrainment of ambient air by the rising plume, condensation of entrained or fuel-derived water vapor and release of latent heat, radiative heat loss from the flame, heat transfer from the smoke to the gas, and the effects of vertical shear in the ambient wind, all pose complexities which tax even the most sophisticated current model. Because of all these uncertainties, some scientists believe that the smoke from large fires will be predominantly restricted to the troposphere, whereas others believe that some smoke will rise rapidly into the stratosphere, where much of it may remain for several months and some of it up to several years.

Plume models could be improved by additional field observations. To resolve some of these questions, it would be desirable to measure the top and bottom altitude, the vertical distribution of the plume, and the downwind dynamics of plumes from a variety of fires as a function of energy release rates. The dependence of these quantities on areal extent and fire intensity, ambient humidity, and ambient wind field must also be determined. The degree of air entrainment and the heat radiated by the fire must be measured, since they are not easily calculated from first principles. It is also necessary to measure the altitude of formation of water clouds in these plumes, to relate the horizontal location of the water cloud to that of the plume, and to relate the region of precipitation to the region in which the plume is located.

Analyses of past experiments will help in understanding the entrainment process. Some of these experiments are large-scale convection experiments in which Doppler radars were used to map the three-dimensional kinematics of isolated convective clouds. Smaller scale, but more intensely buoyant experiments have been performed using oil burners distributed over a large grid exceeding 10,000 m^2. However, reduction and analysis of experimental data in these experiments was not comprehensive and therefore these or similar data must be more fully analyzed to acquire an adequate model of turbulent entrainment. If fires of opportunity, such as large urban, grass, or forest fires, could be studied adequately on short notice, they would provide additional understanding of entrainment processes.

Plume dispersion will also be affected by solar heating and processes acting on mesoscales of 10 to 1000 km. The extent to which solar heating in dense plumes induces mesoscale or large perturbations needs to be determined. Plumes may be buoyant even far downwind from a fire because of solar heating or because they are negatively buoyant due to infrared cooling. This may cause the plumes to rise as they are advected downwind. By contrast, inhomogeneities in the plumes may lead to the development of small-scale convective cells. Potentially, these cells could mix the materials vertically and/or induce condensation and precipitation, which might lead to smoke removal. It is also possible that the reduction of solar heating below the plume will stabilize the lower atmosphere and reduce convection. Careful study of the vertical dynamics of plumes is likely to be fruitful for only large fires, and could be measured by coupling lidar observations of the plume with the meteorological information available from aircraft sensors.*

The dynamics of plumes should depend primarily upon properties which are relatively independent of the fuel source. Hence, measurements made in large forest fires are likely to be directly relevant to the plume dynamics for large urban fires, provided they are of comparable geometry and intensity. These measurements should provide a good verification test for models of plume dynamics.

Cloud Interactions and Removal Processes

A complicated process which needs to be better understood is the interaction between precipitation and smoke, since the residence time of the smoke in the atmosphere may be largely controlled by precipitation. Smoke will often interact with fire-capping clouds where the ratio of cloud mass to smoke is about 10^4:1. In these cases, clouds control the initial injection properties of the smoke and its eventual removal. Many of the effects described in table 1 also depend on the microphysical character of clouds and aerosols and on the atmospheric conditions at the time of the fires.

Smoke-cloud interactions have two parts. First, the removal of smoke by precipitation may be size selective and sensitive to the chemistry, electric charge of the smoke particles, and the electric fields within the cloud. Second, the smoke may modify the clouds either directly by changing the ambient concentrations of cloud nuclei and the cloud's optical properties, or indirectly by modifying atmospheric temperatures and wind fields which control the formation of clouds.

In order to better understand these problems, several different levels of experiments are needed. Laboratory studies will be particularly useful in determining the coagulation characteristics of soot particles and the efficiency of these particles in acting as nucleating sites. In the field, some work has been done to measure particle sizes before and after the smoke from a fire has passed through a cloud. Simultaneous measurements are needed of cloud drop distributions to determine how the smoke has modified the cloud microphysics itself.

Recent theoretical and experimental studies suggest that the presence of electric charges may have a large impact on coagulation of soot and particulates and on the collection of these by cloud and precipitation particles, thereby significantly influencing their ability to remove aerosol particles from the atmosphere. It is likely that the nature of the electric fields normally present in the atmosphere would be altered by nuclear explosions and that increased ionization of particles might occur. Previous atmospheric tests created strong ionization on a hemispheric scale; however, this effect may be countered by the presence of large amounts of smoke, which decrease ion mobility. The extent to which electric charges are important for the "nuclear winter" hypothesis needs to be determined.

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* Historical fires may also provide evidence of the climate changes occurring beneath dense soot clouds. Past accounts of atmospheric effects associated with the large wild fires of 1871, 1910, 1930s, 1950, 1951, 1971, the Siberian peat fires early in this century, and the Australian fires of 1982-83, and others require detailed evaluation.

Well-planned measurements in conjunction with large field fire experiments will include direct sampling by ground towers or aircraft (preferably helicopters) using particle counters. Sample gathering by high-volume impactors will allow laboratory determination of complex refractive indices and nucleation activity. A direct measurement of visibility and hence its alteration can be obtained by tower-mounted lasers or by using the sun as a source. Remote sensing by multiwavelength, ground-based lidar can provide estimates of the size distribution and the backscatter coefficient.

Finally, sooty smoke may not be removed efficiently until photochemical reactions in the atmosphere start the process to deposit soluble materials, such as sulfate, on the soot surfaces. To test this point, the number of cloud condensation nuclei in fresh smoke clouds must be measured. Since smoke is not pure carbon, and since winds may lift much organic and soil material from the surface, there could be abundant condensation nuclei in the fire plumes, as is commonly observed in prescribed and wild fires. The nucleation capability of fresh smoke must be contrasted with that of aged smoke and soot to determine if background photochemical processes make the smoke more susceptible to removal by rainfall.

In addition to determining the particulate properties of fire plumes, the particulate loading in the background atmosphere must be characterized for two reasons. First, the amount of smoke and soot in the ambient atmosphere is not known, either in that half of the earth's atmosphere over the tropics where burning seems to be concentrated, or in the arctic, where observed aerosol containing soot is unexpectedly large. Soot may already play a larger role in the earth's heat budget than has been expected. A better definition this role might allow experimental insight into the interactions of soot with the climate.

Second, the concentration of soot in the tropics results from the mingling of emissions from many different fires as well as from interactions with precipitation processes. An understanding of how the natural processes control the amount of soot can provide a basis for understanding how the process might function after a nuclear exchange.

In order to gain this understanding, it is necessary to obtain better estimates of the number of global fires. This might be done in part from analysis of satellite data currently being gathered or by making field measurements of fires and the amount of soot and smoke generated, its injection altitude, and the amount typically present in the atmosphere.

The existing dry and wet deposition stations of the acid rain network may be able to provide, by additional analysis, estimates of soot removal processes. This information should also help in estimating the efficiency with which rainfall removes smoke from the atmosphere.

Most of those processes having to do with the interaction between smoke and clouds may not depend strongly on whether the smoke is generated by an urban fire or by wild fires, but will depend on injection altitude. Exceptions may be particle size and the abundance of cloud nuclei or the water-soluble nature of the smoke. Data from laboratory and small urban fires will be used to extend atmospheric measurements on wild fires to the urban mass fire case. The drafting committee underscores the important role and need for fire, plume, convection, and microphysical models in planning field and laboratory experiments.

Atmospheric Chemistry

Natural fires may be major sources of NO_x, C_2-C_5 hydrocarbons, CO, and several other gases. These gases are currently of critical importance to the chemistry of the troposphere. Crutzen and Birks (1982) estimated that the fires following a nuclear exchange might triple the amount of CO in the global atmosphere and inject an amount no larger than that from the nuclear fireballs and equivalent to the entire current annual input of NO_x. Originally Crutzen and Birks suggested that these emissions could significantly alter the ozone budget of the troposphere, yielding widespread smog and surface ozone levels that are potentially lethal to some vegetation. Those ideas were based on the presence of high levels of oxidants which are generated photochemically. The presence of large quantities of light-absorbing soot may prevent these oxidants from being initially produced
(Penner, 1983).

With one exception, past studies of the effects of a nuclear war on the stratospheric ozone layer have relied on one-dimensional eddy diffusion models, and none of these models has included dynamic feedbacks. Furthermore, no self-consistent attempt has yet been made to treat this problem in concert with the temperature and dynamic changes that would result from large injections of dust and smoke. The extent to which the ozone layer is depleted and the time it takes to return to normal have been shown to be highly scenario dependent. The larger the yields of individual warheads, the greater the effect on the ozone layer. However, there remains about a factor of two in the uncertainty of the amount of nitrogen oxides (the ozone depletion catalyst) produced per megaton of explosive yield. This uncertainty results from the lack of precise knowledge of the temperature history of air entrained by the fireball and could be reduced by incorporating reaction kinetics in present fireball models.

Besides the catalytic effect of oxides of nitrogen, ozone depletion could result from the attenuation of solar ultraviolet light and from increased temperature due to highly absorbing smoke aerosols in the stratosphere. Such measurements can be made part of the overall fire source experiments. A complete assessment of the ozone layer problem must include two- and three-dimensional models of coupled atmospheric radiation, dynamics, and chemistry. Several such models are at various stages of development.

It has been suggested that a nuclear war could result in an intense photochemical smog with sufficiently high oxidant levels to damage the biosphere throughout much of the northern hemisphere. This could not occur in the absence of sunlight, but only after most of the soot has been removed by wet and dry deposition processes. The extent to which a photochemical smog would occur is highly dependent on the removal rates of atmospheric species in the perturbed atmosphere and on patchiness of smoke. The reduction of oxidant concentrations during the initial darkened period would tend to enhance the lifetimes of many species and allow the further accumulation of reduced compounds such as hydrocarbons, terpenes, and the sulfur compounds emitted by the biosphere. On the other hand, NO_x may still be efficiently converted to the nonphotochemically active form HNO_3, potentially reducing smog formation.

As part of the chemistry and fire experiment research, an assessment of possible toxic gases released particularly from the burning of synthetics could be determined. A number of these substances have been identified, including carbon monoxide, cyanide, dioxins, and furans. The introduction of these gases may be a major additional hazard of nuclear war. Efforts to understand these pyrotoxins is a natural concomitant of some of the proposed fire research and could be studied in this context.

Before the full tropospheric response can be evaluated, both field and laboratory data must be obtained. Laboratory studies of heterogeneous reactions are especially needed. These types of studies are a new field of investigation for which new techniques are currently being developed. Work in this area has been spurred by acid rain studies. Kinetics studies using flow tubes coated with smoke aerosols of various compositions could be utilized to determine the reaction efficiencies of oxidants such as OH, HO_2, and O_3 with aerosol surfaces. Similar measurements on sulfuric acid surfaces have been made in the past. Such reactions could be important in reducing oxidant concentration as well as in oxidizing the particle surfaces so as to render them more hydrophilic and susceptible to removal by wet processes. Complementary studies will be carried out on suspended aerosol particles of varying type and composition. The removal of gaseous species by adsorption on aerosol surfaces will also be studied in this way.

While emission factors for species such as carbon monoxide, nitrogen oxides (NO and NO_2), and many organic compounds have been measured for a few forest fires, this data base needs to be expanded and emission factors and pyrotoxins determined for fires more characteristic of cities.

4. LABORATORY AND FIELD EXPERIMENTS AND ANALYSES

The goals of an experimental plan designed to address the issues discussed in section 3 are summarized in table 2. Because so many different kinds of measurements are required, laboratory and field experiments must be carefully planned to maximize the information content. Since the problem itself can be treated only by extrapolation or modeling, the field experiments must be planned jointly by theoreticians and modelers.

To properly understand the scaling relationships needed for assessing nuclear scenarios, a range of fires of varying intensities and fuel types must be studied for principal fuel bases in urban and wild land. Intrinsic differences between urban and nonurban fires require different approaches. In the nonurban case, it will be possible to focus on the yearly managed fires, directly measuring fuel type and composition, and using aircraft to assess smoke quantity and character.

The lack of a similar opportunity to observe large-scale, intense urban fires suggests a different approach. Instead of an experimental focus on the few largest urban fires, it will be more appropriate to develop a more finely resolved set of laboratory scaling experiments, from bench size to multistructure, effecting the development of confidence in the extrapolation from small to large-scale urban fire effects.

These separate approaches are complementary. Phenomenology acquired from the smaller scale urban-focused experiments will be applicable to nonurban fires. Similarly, it should be possible to apply much of the information on the effects of large wildland fires to the large-scale urban fire environment.

Table 2
Goals of Experimental Program

1. Determine how the gas and particulate yields and properties depend on fire and fuel characteristics. Quantitative scaling rules must be developed to relate variables to these characteristics.

2. Quantify and characterize the properties of the particulate and gaseous emissions from fires.

3. Determine how meteorological parameters affect flammability, fire spread, fire intensity, particle properties, and plume heights.

4. Quantify the interactions between fires, smoke, clouds, and precipitation. These interactions will be on two time scales: prompt effects with highly concentrated smoke and fire-capping cumulus clouds and delayed effects in "ambient" clouds.

5. Determine the ambient smoke levels in a region with many natural sources, such as the tropics, and determine the number of active sources. Quantify the interactions of emissions, multiple sources, and removal processes in order to calculate the regional smoke concentration.

6. Experimentally determine the dynamics of a variety of buoyant plumes in order to both test and constrain plume models.

7. Measure the radiative properties of an array of dense smoke plumes for direct comparison with calculated characteristics based on particle measurements.

Nonurban

Proper source function characterizations require a range of fire size intensities and fuel types. A variety of planned fires will be identified through contacts with the U.S. Forest Service, and the forest services in other countries. For example, the United States and Canadian Forest Services burn large areas each year and very large fires are set in many tropical countries. Efforts will be made to have these groups, or others, start moderate-sized mass fires as well as smaller fires with a variety of fuel sources. Although the initial experiments may be conducted in line fires, it is hoped that the opportunity will develop to study mass fires with multiple ignition sources.

Location, size, and the experimental focus of these wildland fires all argue that the principal measurements should be made from airborne platforms. A model for the experimental design, observations, and equipment needed for these studies is shown in figure 2 and included in table 3. This work is directed at defining the relationship between observed fuel density and composition, fire size and intensity, and the following features:

- Plume Dynamics: Measured by nearby and more remote observations of vertical and horizontal dynamics, the plume temperature structure, ambient temperature and moisture structure, plume morphology and entrainment measurements
- Smoke Quantity and Character: Measured by specific gas detectors and a variety of passive and active particle sampling techniques
- Smoke Optical Properties: Determined from passive visible and infrared photometry, measurements of individual smoke particle scattering phase functions, and if possible, from transmissivity measurements of filter samples
- Capping Cloud Characteristics and Effects: Determine from measurements of cloud droplet size and concentrations, vertical variation of cloud interstitial aerosols and observations of cloud electric fields and particle and droplet charges

Finally, a set of smoke and soot measurements in the tropical atmosphere remote from fire plumes should be made. These measurements could be related to satellite observations of the number and extent of fires throughout the tropics during the several weeks preceding the experiment. The measurements could determine the effects of multiple fires in producing a uniform smoke pall and the scavenging effect of the precipitation. Measurements of soot in commercial aircraft corridors would also be valuable for understanding budgets of high-level soot injection into the atmosphere.

Urban

Both laboratory and large-scale controlled experiments for a variety of structures and urban conditions will be planned to determine the quality and character of emissions from homogeneous and mixed fuel fires. Specific laboratory experiments on urban material will address the basic questions of:

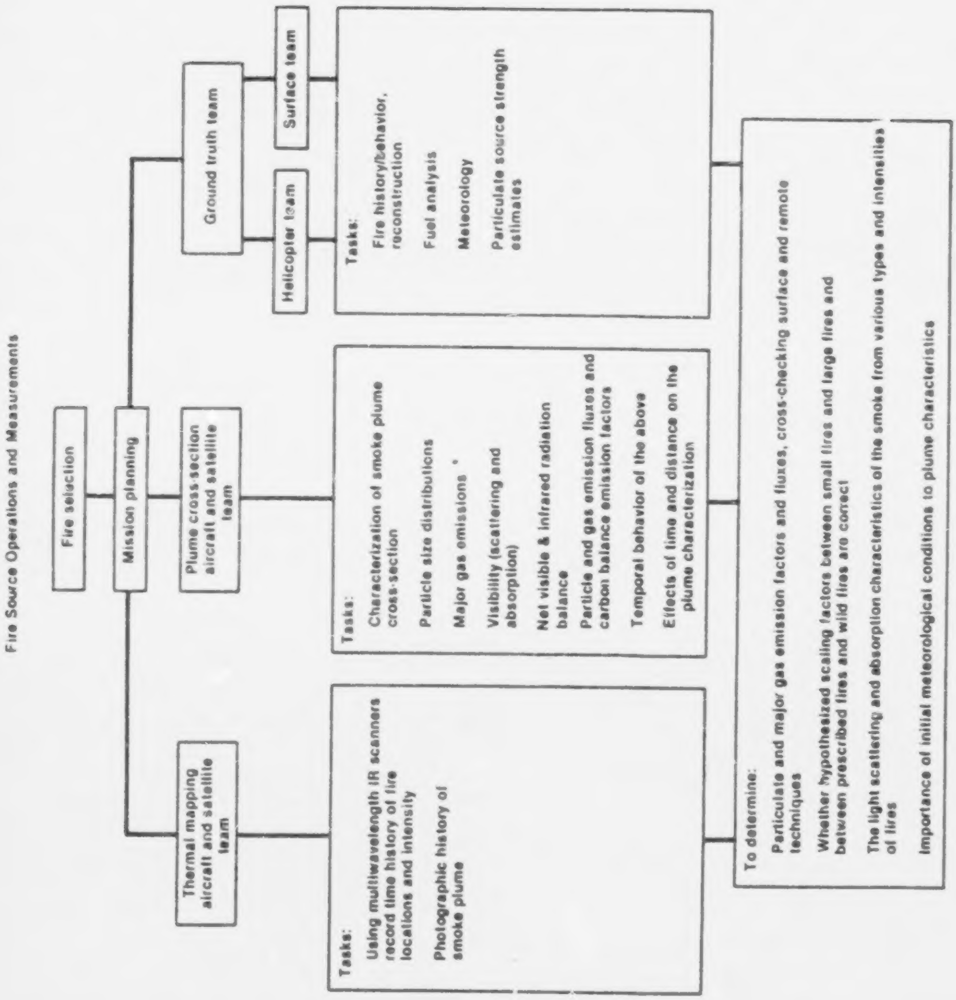
Fire Source Operations and Measurements
Fire selection
Mission planning
Thermal mapping aircraft and satellite team
Plume cross-section aircraft and satellite team
Ground truth team
Helicopter team
Surface team
Tasks:
Using multiwavelength IR scanners record time history of fire locations and intensity
Photographic history of smoke plume
Tasks:
Characterization of smoke plume cross-section
Particle size distributions
Major gas emissions
Visibility (scattering and absorption)
Net visible & infrared radiation balance
Particle and gas emission fluxes and carbon balance emission factors
Temporal behavior of the above
Effects of time and distance on the plume characterization
Tasks:
Fire history/behavior, reconstruction
Fuel analysis
Meteorology
Particulate source strength estimates
To determine:
Particulate and major gas emission factors and fluxes, cross-checking surface and remote techniques
Whether hypothesized scaling factors between small fires and large fires and between prescribed fires and wild fires are correct
The light scattering and absorption characteristics of the smoke from various types and intensities of fires
Importance of initial meteorological conditions to plume characteristics

Figure 2: Initial concept for conducting fire experiment operations and measurements.

Table 3. Parameters to be Measured*

Parameter	Instrument
Local dynamics (vertical updraft in plume, induced winds)	Meteorological boom on aircraft Doppler radar and doppler lidar
Air temperature, plume temperature	Aircraft thermistors
Plume top, bottom altitude, vertical distribution, and downwind extent	Fast-response particle size detector, lidar, or condensation nuclei counter, cinematography
Degree of plume mixing with ambient air	Passive tracer
Fire intensity measurements	Ground-based temperature, airborne spectral scanner
Radiative flux	Flux meter
Fire area	Spectral scanner
Particle mass loading integrating nephelometer, microbalance impactors	Filters, fast response
Smoke composition and vertical distribution	Impacter collections, filter collections
Smoke particle size and morphology	Particle sizing instruments, multiwavelength imaging probe
Smoke optical properties, scattering phase function	Filter collections with laboratory analysis, scatterometer
Smoke visible & infrared optical depth	Sun photometer, infrared photometer
Atmospheric heating in smoke cloud	Flux measurements at several altitudes

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*Multispectral satellite data are useful in determining many of the above parameters.

Presence of H_2O cloud and characteristics	Cloud particle size, spectrometers
Cloud removal efficiency for smoke	Particle size
Gaseous emissions special sensors	NDIR gas chromatographs,

Smoke production for mixed fuels
Degree of coagulation of submicron soot particles
Efficiency of soot particles as nucleating sites
Optical properties of nonspherical smoke and soot particles
Degree of gas-to-particle conversion

It is of interest to know whether the initial states of confined fires might produce significantly more smoke before they break through the structure and become open fires. Laboratory experiments will investigate this effect by controlling the oxygen level of the fire environment. If these experiments suggest that these effects are significant, then larger, more complex experiments will be explored.

The primary issues with respect to urban fires are whether large-scale intense fires are more or less efficient and therefore produce more or less smoke for the same mass of fuel consumed than do smaller, quieter fires, and whether firestorms form.

To study this question, a series of indoor, controlled experiments of varying scales will be planned, to see whether soot and aerosol emission factors can be empirically scaled to larger-sized fires. The effects of nearby heat sources (i.e., other burning structures) will be investigated as well as the effects of oxygen availability and burnout. To integrate these effects into a coherent picture of a mass urban fire, models of soot and smoke formation and near-fire dynamics must be developed. These models will be validated by various scales of controlled experiments.

Once there is confidence in the predictability of emissions from larger scale fires, a set of structure fires will be planned. These will allow at least one check on validity of the scaling experiments described above. However, relating the emissions from a single structure fire to those expected in a large mass fire will require models that can predict the oxygen and thermal environment near the smoke formation region. The development of these models must be linked to the smaller scale experiments described above in order to be credible. Fire model research must be planned in parallel with fire experiments to ensure maximum application of the experiments.

Fire Rapid-Response

It may be possible to take advantage of unplanned urban or vegetation fires if such fires can be immediately recognized and if an observational program can be organized to respond rapidly. Both the NOAA polar-orbiting and geostationary satellites are capable of detecting fire plumes and smoke areas. In addition, the 3.8 micrometer channel on board the polar-orbiting satellites can detect the fire areas or so called "hot spots." Maximum resolution on both satellite systems is 1 km but most operational data are at 4 km. Even at this resolution, fire activity is easily seen on satellite imagery (see figure 3). Forest, rangeland, tundra, and slash-and-burn agriculture fires have been detected with the NOAA satellite data and are available in digital or image format from the NESDIS satellite archive. Some of the forest and tundra fires in Siberia and Canada have generated smoke that covered areas as large as 50^{o} longitude x 5^{o} latitude (approximately 1.5 million km^2) and that lasted as long as three weeks. Visible and thermal infrared satellite data in conjunction with conventional data can provide

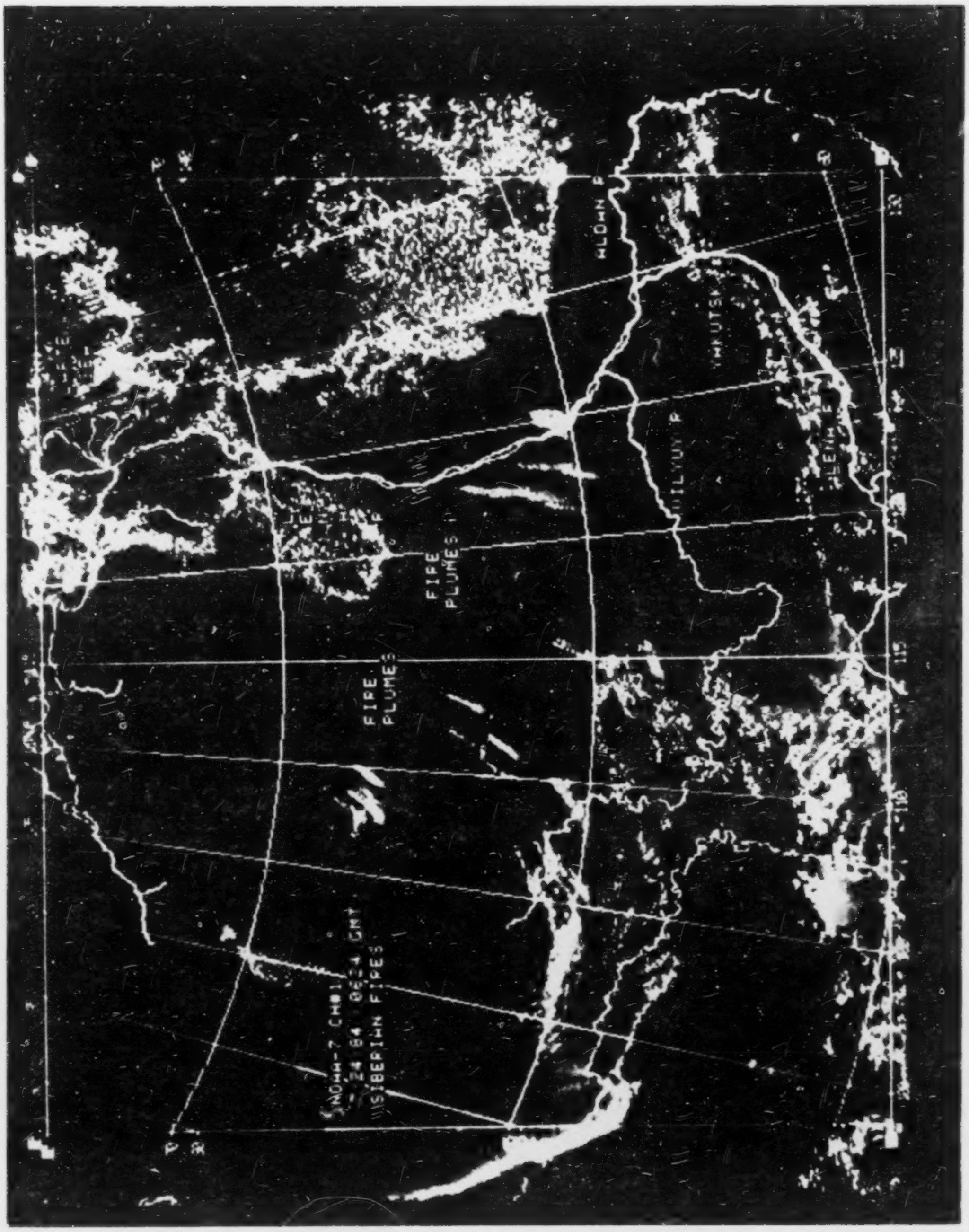
ALDAN R
YAKUTSK
VILYUY R
LENA R
FIRE PLUMES
FIRE PLUMES
NOAA-7 CH#1
7 24 84 0624 GMT
SIBERIAN FIRES
130
125
115
110

Figure 3: NOAA-7 imagery detected several large smoke plumes in Siberia from 10 to 25 July 1984.

information on fire source areas, fire spread, smoke flow, smoke altitude, smoke area, smoke residence time, radiation balance effects, and smoke opacity. Use of multispectral data on the polar-orbiting satellites may also provide information on smoke particulate sizes.

The reduction in solar radiation at the earth's surface due to large fires can be directly measured by existing solar radiation networks located at 34 meteorological stations in the United States.

Federal agency and university scientists were able to respond rapidly to the eruption of Mount St. Helens and organize an observational program to measure and track the volcanic plume. Based on this experience, it is likely that a similar rapid response can be organized for a major fire, at least in the United States.

Other Experiments and Related Studies

Many of the climate effects following a nuclear war involve large-scale radiative interactions between aerosols and the atmosphere. Of course, there are no events in nature which duplicate these effects exactly. However, large dust storms such as those that occur continually over the Sahara desert may serve as a limited natural analogue of smoke produced by nuclear exchange. For example, Brinkman and McGregor (1983) report dust storms over Nigeria with optical depths up to 2, reductions in total solar radiation of 28%, and temperature decreases as large as 6°C. The qualitative similarity with the nuclear winter scenario suggests that these dust storms might usefully be sampled and modeled.

Because of the high altitude and high albedo of the dust, it can greatly enhance the effects of the soot clouds below. A wide range of dust studies are possible, including dust generated in test chemical explosions; new studies of archived particles sampled from above-ground nuclear weapons tests, and flights through future dust clouds.

Experimental studies could presumably be conducted using standard radiosonde stations to collect information on atmospheric temperatures as well as instrumented aircraft to measure the altitude and extent of the dust cloud, the cloud particle properties, and the radiative fields. There are, of course, no direct analogues of nuclear explosions. Yet these analogues are useful in testing some aspects of climate simulations. Other possible naturally occurring analogues for assessing the nuclear effects are summarized in table 4.

Table 4. Analogues*

Process	Analogues	Relevant observations
Soot particle source function	Urban fires (Moscow, 1812) San Francisco, 1906, etc.)	Total particle mass, Particle size distribution, Vertical distribution, Horizontal distribution, Optical properties of particles, if available
	World War II firestorms from conventional bombing (Dresden, Hamburg, Tokyo) and from atomic bombing (Hiroshima, Nagasaki)	
	Tropical slash-and-burn agriculture	
	Historical forest fires	
	Bush fires	
	Arctic haze	
	Land-clearing open fires	
	Deliberate experiments (smoke pots, burning vehicle hulk, carbon black dust)	
Dust particle source function	Volcanic eruptions	(Same as soot particles)
	African dust storms	
	Arctic haze	
	Battlefield dust experiments	
	Road dust	
Atmospheric dynamic response	Martian dust storms	Decreased baroclinicity Induced cross-equatorial transport
Hydrological cycle	African dust storms	Decreased convection

Climate response	Asteroid impact 65 million years ago and other apparent impact-induced extinction events	Extinction of dinosaurs and many other species, presumably from surface cooling and darkness
	Seasonal cycle	Summer to winter change in forcing and temperature response about the same as nuclear winter scenarios, but slower
	Diurnal cycle	Day to night change in solar energy forcing and surface temperature response similar to some nuclear smoke scenarios
	Saharan dust	Reduced surface air temperature
	Great Smoke Pall (Canadian forest fires - 1950)	Reduced daytime surface air temperature
	Volcanic eruptions	Immediate surface air temperature response (cooling day and night - Krakotoa, cooling during day and warming at night Mt. St. Helens)
		Rapid (1 to 2 months) cooling over continents
		Hemispheric cooling with maximum amplitude in winter polar regions 2 and 3 years after eruption

Compiled by Alan Robock, University of Maryland

5. IMPROVEMENTS IN MODELING ATMOSPHERIC PROCESSES

Radiation

Particles in the atmosphere directly affect the earth's climate by interacting with solar and thermal radiation to alter radiative heating rates within the atmosphere and at the ground. These changes in heating rates can lead to modification of temperature, precipitation, and wind fields and are crucial in defining the potential climatic disturbance caused by nuclear war-generated aerosols.

Detailed radiative transfer calculations have provided the approximate magnitude of the change in atmospheric heating rates for plausible properties of the smoke and dust particles that might be produced in a nuclear exchange. If large amounts of carbon smoke are injected into the middle and upper troposphere and lower stratosphere, these atmospheric layers would experience a large increase in the solar heating rate. The land surface below, deprived of much solar radiation, would initially experience a cooling. Heating in the troposphere would be due chiefly to the absorption of sunlight by the smoke; cooling at the surface would be due to reduction in sunlight reaching the ground. A warming of the lower stratosphere and a cooling of the entire troposphere may characterize later times when most of the smoke has been removed from the troposphere but dust and some smoke remain in the lower stratosphere.

Published estimates of the radiative effects of nuclear exchanges have provided rough estimates under different scenarios and assumptions. The major uncertainties in these estimates result from a lack of direct measurements of radiative properties and effects of smoke aerosols. Major radiative properties directly determining the alteration of heating rates include (1) visible and infrared optical depths (a measure of the probability of particles interacting with light), (2) single scattering albedo (ratio of the scattering cross-section to the sum of the absorption and scattering cross-sections), and (3) scattering phase function (probability of radiation being scattered in various directions).

A significant improvement in understanding the radiative effects of nuclear exchanges could be obtained by directly measuring the radiative characteristics of smoke aerosol during proposed fire source experiments. Such measurements should be taken close to the burn as well as far downwind. Concurrent measurements of the pre-burn characteristics of the fuel source and fire intensities as well as related size distribution and composition would provide a basis for parameterizing the radiation effect.

A problem which has not yet been addressed by climate models is the nature of the modification in the radiative properties of water clouds engendered by smoke. This is a potentially important problem in view of the central role precipitation plays in removing smoke particles from the atmosphere and in view of the possible alterations of the precipitation character of clouds that could follow from changes in the radiative properties. While this problem is more difficult to address experimentally than that of the radiative properties of the smoke particles, initial estimates can be made by measuring the size distribution, composition, radiative properties, and radiative heating rates within the water clouds that frequently cap fire plumes or within water clouds that may form in the smoke plumes of large forest fires.

While high resolution radiative transfer algorithms have been used in one-dimensional, radiative-convective models, a less complete treatment of radiation has been used in calculations made with dynamic models. Since dynamic models, especially global and mesoscale models, will play a central role in future attempts to improve the estimates of the climatic effects of nuclear war, high priority must be placed on incorporating fast, yet accurate and complete radiation algorithms into these models.

Radiative transfer codes used in studying the aerosol problem relevant to the nuclear war scenario should be tested by comparison with other similar codes. Radiative transfer codes could be tested in isolation by using a standard aerosol configuration including solar scattering and infrared absorption.

Much of the evaluation of atmospheric effects of nuclear war depends on modeling atmospheric processes on a variety of spatial scales. Three major scales of interaction are plume-cloud, 1-100 km; mesoscale, 100-1000 km; and global, greater than 1000 km.

Plume and Cloud Interaction Modeling

Plume-cloud models are essential for two reasons:

> The lifetime of smoke in the atmosphere is determined primarily by the initial height of injection and by precipitation scavenging that requires modeling of the spatial scale of individual clouds and ensembles of clouds and synoptic scale systems. Surveying in the initial plume should be considered as well as longer term scavenging on the larger scale.
>
> The effect of smoke and dust on clouds and precipitation and therefore on vertical and horizontal transport needs to be parameterized for use in large-scale climate models that cannot explicitly resolve individual clouds. Also the effect of clouds and precipitation on smoke and dust needs to be parameterized for large-scale models.

A major effort in calculating local-scale circulation in conjunction with the evolution of aerosol microphysics is also needed. Plume and cloud models have been developed for many applications, but some further modifications are needed for application to the nuclear war problem.

Microphysical questions that need to be considered include (1) overseeding, (2) changes in aerosol characteristics due to passage through nonprecipitating clouds, (3) effects of aerosols on precipitation formation, (4) importance of attachment of aerosols to droplets, (5) how smoke particles compete with natural aerosol as condensation nuclei, (6) freezing nuclei, (7) how ice phase evolution is affected by smoke and dust particles, and (8) whether the presence of ice affects scavenging rates and efficiencies.

Plume models are primarily one dimensional. Some involve cloud processes and would be appropriate for predicting cloud top heights and the height to which pollutants would rise. Similarly, one-dimensional cloud models offer a way to analyze atmospheric soundings to determine the depth of convection to be expected. Such models have been used extensively in cooling tower problems. Extreme heat and vapor inputs could be tested for their effects on convection. The efficiency of one-dimensional models would allow many different soundings at many different places and times of the year to be used to predict the penetration height of clouds of various widths.

Multidimensional, time-dependent, plume-cloud models are needed to attack the aerosol-cloud interaction problems mentioned above, as well as the cloud venting and overshoot problem. Some of the various cloud models in both two and three dimensions which are available are given in table 5, which is taken from the National Academy of Sciences report (1981). Some of these models treat both ice and water microphysics; some include many particle sizes, allowing for the evolution of the drop size distributions, while others have highly parameterized microphysics and assume a typical size distribution. Some of the models allow for aerosol fields and simulate interactions with the motion fields. Cloud model grid intervals vary from 100 to 1000 m; domains vary in the vertical from 10 to 20 km and in the horizontal from 10 to 100 km or more; some models have more complex turbulence formulations than others. Some of the models simulate heat fluxes and evaporation of water vapor at the earth's surface, which could be modified to simulate the much larger inputs to be expected from fires. These cloud-scale models need to be coupled with larger scale models in an interactive fashion to predict the spread of soot and dust or noninteractively to check for consistency among the predictions of the various scale models. A major review of existing cloud scale models is needed to assess their utility for evaluating the consequences of nuclear war.

Local-scale models fit in with the field experiments and are necessary to aid in the interpretation of the field observations. In turn, the observations are necessary to check the adequacy of the physics used in the models and to improve the models.

An overall integrated cloud modeling effort enhanced by new observations needs to be developed. An extensive computational study is needed of the washout capability and the venting properties of clouds under the extreme conditions resulting from a nuclear war.

Mesoscale and Global Effects

Theoretical analysis and preliminary model results indicate that large amounts of smoke particles injected high in the atmosphere and spread over much of the globe have the potential for significantly reducing continental surface temperatures if the particles remain in the atmosphere for more than several days. It is the role of mesoscale and global circulation models to simulate the regional and global climatic effects of nuclear war-generated smoke and dust particles.

Mesoscale circulation models and global circulation models are fundamentally similar, differing primarily in horizontal resolution and the detail in which they treat atmospheric processes. Global models are designed

Table 5: **Summary of Cloud-Scale Models Active in 1980**

Model Identification	Domain	Emphasis	Contact	Remarks
One-Dimensional Steady-State Models				
BUREC	20 km (vertical)	Cloud top, vertical motion, seeding potential	Matthews	
SDSMT	20 km (vertical)	Cloud top, vertical motion, seeding potential, plume transport	Hirsch, Orville	Used for maximum hailstone size prediction
NOAA/ERL	20 km (vertical)	Cloud top, vertical motion, seeding potential	Woodley	Used to predict covariates in weather modification project
CSU/1D	20 km (vertical)	Cloud top, vertical motion, seeding potential	Cotton	
One-Dimensional Time-Dependent Models				
SDSMT	20 km (vertical)	Cloud microphysics, hail prediction	Farley, Orville	
Two-Dimensional Models				
U. Ill./2D	48 km x 14 km	Single clouds, severe storms	Soong, Wilhelmson	Axisymmetric and slab symmetric models
U. Wisc./2D	~50 km x 15 km	Severe storms	Schlesinger	Liquid bulk water microphysics, slab symmetry
CSU/2D	35 km x 17 km	Tropical Cu, mountain Cu	Cotton	Slab symmetry
NCAR	18 km x 12 km	Detailed cloud microphysics, ice and liquid processes	Hall	Slab symmetry
SDSMT/2D	20 km x 20 km	Hailstorms, cloud electrification, cloud modification	Orville, Farley, Helsdon	Some detailed ice microphysics, slab symmetry
Hawaii/2D	6 km x 6 km	Detailed microphysics, hailstone growth, cloud electrification	Takahashi	Axial symmetry
RAND	10 km x 10 km	Tropical Cb, ice bulk water microphysics	Murray, Koenig	Axial symmetry
U. Wash./2D		Detailed microphysics, particularly ice phase	Hobbs	Axial symmetry
Three-Dimensional Models				
U. Wisc./3D	48 km x 48 km x 14 km	Severe storms	Schlesinger	Liquid bulk water microphysics
CSU/3D	35 km x 35 km x 17 km	Tropical Cb, mountain Cb	Cotton	Some ice bulk water microphysics
NCAR/Ill./3D	48 km x 48 km x 16 km	Severe storms	Klemp, Wilhelmson	Liquid bulk water microphysics
NCAR	50 km x 50 km x 15 km	Hailstorms	Clark	Liquid bulk water microphysics
NCAR	10 km x 10 km x 17 km	Tornado genesis	Rotunno, Klemp	Nested in 3-D cloud model
Hawaii/3D	6 km x 6 km x 4km	Tropical Cu, detailed liquid microphysics	Takahashi	
NOAA/GFDL	3 km x 3 km x 2.5 km	Tropical Cu	Lipps	Liquid bulk water microphysics

to simulate the large-scale features of the entire global climate over time scales ranging from days to years. Typical horizontal grid resolutions in global models are 200 to 1000 km. Mesoscale models, typically used for weather forecasting and research, are usually applied to a bounded region of the globe (e.g., the eastern U.S.), and thus are used to simulate weather conditions for only a few days at a time. Global models, on the other hand, can represent many features of the present global climate with reasonable accuracy and are in a somewhat more advanced state of development than that of mesocale models. However, mesoscale models trade simulation length and computational domain for enhanced horizontal grid resolution, typically 10 to 100 km. The increased resolution facilitates the simulation of meteorologically important features such as fronts and convective complexes. But neither type of model is yet well adapted for the large perturbations involved in nuclear war climate simulations. Similar enhancements are needed in both types of models, therefore the following discussion applies to both.

The principal physical processes which must be incorporated in a general circulation model for the study of nuclear winter are indicated schematically in figure 4. The portion of the figure above the dashed line shows those processes which are found in global models designed for studies of the present climate. The physical processes in the lower half of the figure are pivotal to the effects of nuclear war but have generally received little study. Furthermore, because aerosols have a relatively small impact on the present climate, even for major injection events such as large volcanic eruptions, it will be difficult to test the validity of such processes with naturally occurring analogues. The paucity of relevant observational analogues will require greater than usual emphasis on stand-alone tests of the modeled physical processes. Also, transient regional-scale situations involving heavy aerosol loading, e.g., Saharan dust storm clouds, could provide some model validation.

Aerosols can be transported by subgrid-scale turbulent mixing processes ("convective processes" in figure 4). The most important such process is the vertical mixing resulting from turbulence driven by convective instability or wind shear. Because these processes occur on spatial scales which cannot be resolved by the coarse grid of a large-scale model, the resulting diffusive transport of various material properties must be parameterized. Because vertical turbulent diffusion may also be an important transport mechanism for smoke and dust particles, a more elaborate description of turbulent processes is required for studies of a nuclear winter than is presently available. For example, second-order closure models of turbulence are more realistic and detailed and are not highly "tuned" to the present climate, a frequent criticism of the application of global models to the nuclear winter problem. Fortunately, turbulent mixing processes are quite important for the unperturbed atmosphere, so the validity of these more sophisticated turbulence models may be assessed through benchmark simulations of the present climate.

Proper specification of the initial injection of smoke and dust ("fires, fireballs" in figure 4) into the large-scale atmospheric circulation for use by global models is the major objective of the experimental program discussed in the preceding chapter. The effect of the fire source can also be investigated with a series of models: (1) combustion models on the scale of a single building; (2) multiphase reactive-flow models on the scale of several kilometers to study combustion efficiency, adequacy of oxygen flow to the

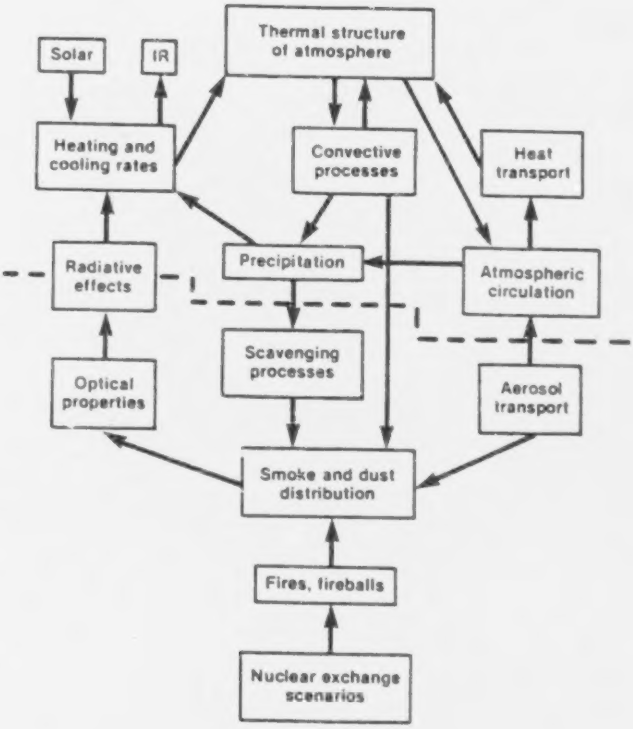
Solar
IR
Thermal structure of atmosphere
Heating and cooling rates
Convective processes
Heat transport
Radiative effects
Precipitation
Atmospheric circulation
Scavenging processes
Optical properties
Aerosol transport
Smoke and dust distribution
Fires, fireballs
Nuclear exchange scenarios

Figure 4: Principal physical processes required in global models to study the effects of nuclear explosions. Those processes above the dashed line are generally found in most global models; those below are not and require a concentrated effort.

fuel, soot production, and lofting; (3) cloud physics and plume rise models to study local precipitation scavenging in cloud-capped plumes; (4) multiphase fireball models to study lofting of dust in nuclear fireballs; (5) and mesoscale models to study transport, dispersion, and scavenging on scales out to several hundred kilometers and to study the effects of nuclear explosions, fires, and resulting clouds on the mesoscale atmosphere. At this largest scale, a spatial average of the smoke and dust distribution from these smaller scale models can be mapped onto the coarse grid of a global model to define the source term.

The efficiency of scavenging of smoke and dust by wet and dry processes is important on all scales. Treatments of scavenging processes must be included in most of the source-term models mentioned above. For climate consideration, the particles which interact with sunlight most effectively (per unit mass) are submicron; for such particles, removal by sedimentation is relatively inefficient. The principal mechanism for removal of submicron particles in the lower atmosphere is precipitation. Modeling of precipitation scavenging in both global and mesoscale models depends on: (1) prediction of precursor conditions for precipitation, (2) vertical and horizontal (subgrid) distribution of precipitation, (3) efficiency of removal of particulates, (4) proper simulation of precipitation-inhibition or enhancement conditions associated with the dense smoke and dust clouds themselves, (5) re-evaporation and recycling of condensed material.

The first issue focuses on the ability of the model to simulate properly the upward flux of water vapor into the atmosphere and its transport to regions of large-scale uplift or convective activity, where it may be precipitated. A number of studies on precipitation climatology have been published, some with very successful simulations (e.g., S. Manabe and Hollaway, 1975). Simulated precipitation rates cannot be grossly in error since the latent heat release, which is an important atmospheric energy source, and the atmospheric dynamics, are often impressively simulated. Because the injection of smoke and dust and the major climatic impacts of a nuclear winter will occur over the midlatitude continents of the northern hemisphere, the outcome may be more sensitive to the distribution of precipitation than the average unperturbed climate.

Another problem in meso- and global scale modeling is determining the vertical distribution of latent heat release, which is important when aerosol scavenging is involved. The removal of aerosols in the atmosphere depends on processes in the troposphere and stratosphere. Even if a model were to predict the correct amount and geographical distribution of precipitation, in the lower troposphere the smoke and dust in the atmosphere will not be removed properly if the condensation is improperly distributed vertically or horizontally in the troposphere. Experimental results have generally shown a high scavenging efficiency for particles injected into the region of precipitation formation. However, scavenging efficiency parameterizations that are based upon observed aerosol residence times in the unperturbed atmosphere are inappropriate, since they implicitly assume the present vertical distribution of temperature, moisture, clouds, and precipitation formation.

After the initial injection of aerosols by nuclear explosions and fires, dense smoke clouds may modify the atmosphere in ways which could inhibit scavenging of the smoke. If the troposphere was stabilized by a combination of heating in the smoke clouds and (land) surface cooling, convective processes and the upward flux of water vapor from the surface could be inhibited over land resulting in greatly reduced convective precipitation. It is less clear what might happen over the oceans, where the surface temperature will be relatively unchanged. It also remains to be seen what role regional and continental scale inhomogeneities in the smoke cloud will play in generating local circulations and, possibly, local convective activity.

Simulation of the injection, dispersion, and scavenging of smoke emissions requires meso- and global-scale models not yet fully developed or coupled. Existing models treat processes in the upper half of the diagram and include multiscattering and absorption factors. Aerosol source functions, aerosol transport, and scavenging must also be added to present models, and simulation of convection and radiative processes must be improved. Major progress in this area requires considerable new research efforts.

The calculation of rapid transients in surface temperature is a crucially important aspect of large-scale circulation model studies of the nuclear war-climate problem. Many present models include only a zero heat capacity land surface and crude (if any) planetary boundary layer parameterizations. The importance of a better simulation of low-level cloud and radiation fog formation to the surface temperature transients must be studied using more detailed parameterizations than are presently incorporated. A combination of planetary boundary layer parameterization and improved surface physical processes (e.g., heat flow into the surface, effects of vegetation, local stability-dependent surface fluxes) must be included in any global model used for nuclear war-climate research before we can have much confidence in the detailed time and space evolution of surface temperature. Surface and planetary boundary layer enhancements could be tested using the diurnal isolation cycles as a surrogate forcing.

Another type of modeling activity must also be performed. Although much of the debris from nuclear explosions and fires might be injected into the troposphere, substantial dust and possibly soot will be ejected into the stratosphere. Also, soot might rise into the stratosphere. Hence stratospheric dynamics may be as important as troposphere dynamics. The significance of dust and soot lifted into the stratosphere by nuclear explosions is that the stratospheric debris could have a long lifetime - on the order of years - and in certain scenarios large quantities of material may be placed into the stratosphere. The dust will have different optical properties than smoke and will be placed primarily in a different region of the atmosphere. Another class of global models, one devoted to stratospheric dynamics, will be needed to properly evaluate the spreading of the stratospheric debris. Significant dust loadings, or significant movement of soot into the stratosphere, could result in stratosphere clouds with enough optical depth to perturb the energy balance at the ground for long periods of time. Tropospheric models will not be adequate by themselves to properly consider this interaction. Hence an interplay between stratospheric circulation models and tropospheric ones will be needed.

In summary, the following specific areas where these models need to be improved include:

Vertical transport and convection parameterizations for heat, moisture, and momentum from the earth's surface through the planetary boundary layer and troposphere under conditions possible after a nuclear exchange.

Surface parameterizations that permit accurate simulations of diurnal cycles and rapid surface temperature changes following a dust and smoke injection.

Hydrologic cycle representation that can accommodate changes in cloud and precipitation processes over a wide range of large-scale atmospheric states. Reformulation of parameterizations can provide assurance that the representations are capable of at least minimally handling dust and smoke interactions.

Incorporation and verification of aerosol processes in cloud, meso- and global-scale models that treat the injection, dispersion, and scavenging of smoke and the effects of smoke on radiative transfer and cloud physics.

Transport of aerosols from source regions, both horizontally and vertically (including transport on grid-scale and parameterized subgrid-scale). Simulations assuming unperturbed atmospheric dynamics have already been done and coupling of microphysical and dynamic models is now underway.

Precipitation scavenging and microphysics, including treatment of subgrid-scale scavenging processes, rain and ice interactions with particles, etc. in ways that remain accurate under a range of possible perturbed atmospheric conditions. Cloud models are already being modified so that algorithms used in large-scale models can be calibrated. The modelling studies will make use of and provide guidance for other elements of the program.

Tropospheric chemistry and trace gases, particularly water vapor components and their infrared properties.

6. AGENCY RESPONSIBILITIES

Much of the work on evaluating the atmospheric effects of nuclear war has been done by small groups of government and nongovernment scientists. Those activities which have had federal sponsorship to date are summarized below by agency:

Department of Defense/Defense Nuclear Agency

Major responsibility for supporting nuclear effects research in the United States: fire research, modeling, and representative target data base development.

Department of Energy/Lawrence Livermore National Laboratory

Target data base development, source material, cloud-mesoscale dynamics, atmospheric modeling, firespread, microphysics, biological effects, and integrated analysis.

Department of Energy/Los Alamos National Laboratory

Mesoscale and global model development.

National Aeronautics and Space Administration/Ames

Source materials, radiative models, aerosol physics, stratospheric modeling, and analogue studies.

National Center for Atmospheric Research and University Scientists/ National Science Foundation

Global model development and sensitivity studies

Federal Emergency Management Agency

Supports research relevent to emergency management

National Oceanic and Atmospheric Administration/National Climate Program Office

Coordination of interagency research plan.

The present research effort encompassed by the above in FY 1984 is about $3.5 million funded by DOD and DOE. The DOD funds have supported internal research and also activities at Los Alamos, NCAR, and some universities. Related work at NASA and universities has resulted from other projects or studies such as atmospheric effects of dust storms on Mars and general modeling and climate studies.

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APPENDIX A: National Research Plan Committees

COMMITTEE A: INTERAGENCY REVIEW COMMITTEE

John V. Byrne, Administrator, NOAA (Chairman)

Dr. Marvin C. Atkins
Deputy Director, Science and Technology
Defense Nuclear Agency

Dr. Eugene W. Bierly
Director, Division of Atmospheric Science
National Science Foundation

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Office of Policy, Planning and Evaluation
Environmental Protection Agency

Dr. Joseph O. Fletcher
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NOAA

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NOAA

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NASA

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Dr. Charles B. Philpot
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Department of Agriculture

Dr. Alvin W. Trivelpiece
Director, Office of Energy Research
Department of Energy

Honorable Richard L. Wagner, Jr.
Assistant to the Secretary of Defense (Atomic Energy)
Department of Defense

APPENDIX A

COMMITTEE B: DRAFTING COMMITTEE

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Captain Donald Alderson
OSD/USDRE/OATSD (AE)

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FEMA

Dr. John Birks
University of Colorado

Dr. Joseph Bishop
FEMA

Mr. Jack Campbell
Environmental Protection Agency

Dr. Robert D. Cess
State University of New York

Dr. Vernon Derr
Environmental Research Laboratory
NOAA

Mr. Peter Lunn
Defense Nuclear Agency

Dr. Michael MacCracken
Lawrence Livermore National Laboratory

Dr. Robert Malone
Los Alamos Laboratory

Dr. Michael May
Lawrence Livermore National
Laboratory

Dr. Harold D. Orville
South Dakota School of Mines
and Technology

Dr. James Pollack
Ames Research Center, NASA

Dr. Lawrence Radke
University of Washington

Dr. Starley Thompson
National Center for Atmospheric
Research

Dr. Brian Toon
Ames Research Center, NASA

Dr. Darold Ward
U.S. Forest Service

Dr. Martin Yerg
National Climate Program Office

APPENDIX B: Ranges of Uncertainties in "Nuclear Winter" Calculations

(prepared by Michael C. MacCracken, Lawrence Livermore National Laboratory)

TABLE B-1: HOW MUCH SMOKE IS GENERATED?

Factors	Oft-Used Value	**Range**	Depends on:
Number of explosions combustible targets	6,000	**Few to several thousand or more**	Scenario
Fraction of unburned,	20%	**Few to 100%**	**Targeting strategy,** overlap, likelihood of ignition
Combustible fuel density (g/cm^2)	~3 in cities 0.5 in forests	0.1 to 10 g	**Target type, for forests depends on time of year**
Area per fire (km^2)	200	10-1000	**Yield, target, weather, likelihood of spreading, burst height, topography, fluence for ignition**
Lofted aerosol fraction <1.0 μm	~3 x 10^{-2}	10^{-3} - few 10^{-2}	**Nature of fuel, nature** of fire, fraction of fuel burned
Total aerosol mass (g)	2 x 10^{14} = 200 Tg	10-1000 Tg	**Present U.S. forest fire injection is about 10 Tg/yr, global atm soot loading** < 1 Tg

TABLE B-2: HOW HIGH DOES SMOKE PLUME GO? HOW MUCH IS INJECTED?

Factors	Oft-Used Value	Range	Depends on:
Plume height	Up to 10 km	Few to 20 km	Type of fire (urban, forest, etc.), fire size and intensity, atmospheric temperature structure, winds, etc.
Fraction lofted to stratosphere via firestorm	5%	0-20%	Fire intensity, atmospheric temperature structure, winds, etc.
Particle transformation via:			
Chemistry	Neglected	Changes composition	Particle size, composition, number density, atmospheric conditions, relative humidity, clean air entrainment, temperature, etc.
Coagulation	Slow	Could be fast at early time	
Cloud/prrticle interaction	Neglected	Changes size distribution and optical properties of cloud	
Rainout, scavenging	25%	Few to > 50%	

TABLE B-3: WHAT ARE THE SOLAR AND INFRARED RADIATIVE EFFECTS?

Factors	Oft-Used Value	Range	Depends on:
Smoke reduction of Northern Hemisphere solar radiation (light) reaching surface (optical depth = 3)	$\gtrsim$90%	0 in clear areas, up to 99+% under thick smoke clouds	Composition, amount, particle size distribution, particle shape
Size distribution	Peaks ~ 0.1 μm, log-normal	Initially not log-normal, size changes in time	Formation process, coagulation and scavenging processes
Single scatter albedo of smoke particles	0.5	0.5-0.8	Particle composition, shape, etc.
Composition	Soot coated by hydrocarbons	Wide range depending on mixture of fuels	Formation processes, chemical evolution
Shape	Spherical	May be strongly nonspherical (aspect ratio of 10 is possible)	Formation and coagulation processes. Shape probably not important except for large aggregates
Smoke effect on IR radiation	Negligible	Could be large effect for thick smoke cloud	Size distribution, shape, and composition of smoke particles

TABLE B-4:, THEN WHAT HAPPENS?

Factors	Oft-Used Value	Range	Depends on:
Mesoscale transformation and scavenging	Ignored	Could be very important	Weather conditions, dynamic perturbations
Mesoscale spreading	Unperturbed spread in vertical, very rapid speed in horizontal direction	Horizontal and vertical spreading rate could be slowed or accelerated dramatically, depending on dynamic interactions.	Weather, self-induced heating and spreading of smoke, creation of patchiness by storms
Hemispheric transformation and scavenging	Unperturbed	Could be accelerated or slowed	Perturbation to mesoscale (e.g., ocean-land contrast) and global dynamics and atmospheric vertical structure (convection)
Hemispheric spreading	Instantaneous	Likely slow, especially to Southern Hemisphere, unless self-induced	Season, windspeed, perturbation to atmospheric circulation pattern
Temperature change	Severe and rapid cooling of land	Small to severe	Smoke patchiness, ocean buffering, perturbed dynamics, time of year, cloudiness, altitude of injection, optical properties of smoke, etc.

TABLE B-5: WHAT ARE THE ECOLOGICALLY IMPORTANT CHANGES?

Factors	Oft-Used Value	Range	Depends on:
Reduction in available sunlight	90%	Few-100%	Spreading rate of aerosol, patchiness, smoke properties
Mid-latitude temperature change on land	-30 to -40:C	Near zero to -30:C or more, will be larger in summer than winter	Season, latitude, extent of ocean buffering, topography/geography, vertical and horizontal spreading rate of aerosol, climatic feedbacks
Tropical and southern hemisphere temperature change on land	-20 to -40:C	Near zero to -20:C	Rate and degree of spreading of smoke, scavenging rate of smoke, ocean buffering of temperature change
Duration of temperature change	Few months, with immediate onset	Few days to year, with possibly rapid onset under some conditions	Lifetime of soot in atmosphere, soot distribution and rate of spread
Precipitation change	Decrease	Increase or decrease	Location (coast vs. inland), latitude, change in atmospheric stability, possible early scavenging in convection induced by smoke plume
Surface winds and storminess	Increase	Increase or decrease	Dynamic response to temperature contrasts and perturbations

DOD Says "Nuclear Winter" Bolsters Its Plans

Congress is disappointed by a report on the impact of soot on nuclear strategy

To some weapons experts and arms control advocates, the recent discovery of a climatic phenomenon known as "nuclear winter" offered a powerful reason to rethink the basic assumptions underlying U.S. nuclear strategy. Not so, says the Defense Department. In a controversial new report to Congress, the Pentagon has concluded that a "nuclear winter" may never occur, and that in any event its discovery only strengthens the arguments for existing weapons modernization plans and arms control policies.

"The issues raised by the possibility of effects of nuclear war on the atmosphere and climate only strengthen the basic imperative of U.S. national security policy—that nuclear war must be prevented," says the 17-page report, entitled *The Potential Effects of Nuclear War on the Climate*. "For over three decades, we have achieved this objective through deterrence and in the past 20 years we have sought to support it through arms control. Now, through the Strategic Defense Initiative, we are seeking a third path to reduce the threat of nuclear devastation."

Specifically, the report suggests that a number of recent weapons developments diminish the chance of war, as well as the likelihood that a nuclear exchange could loft enough dust and soot to prevent heat and light from reaching much of the earth's surface, thereby creating a "nuclear winter." These include the deployment of "systems which are more discriminating" or accurate; the "development of a wide range of combinations of targeting and system selection options" that give the United States "escalation control" or the ability to fight a limited nuclear war; and a trend toward increased targeting of military assets, not urban centers. These will have the effect of "reducing unwanted damage" that can lead to severe climatic perturbations, the report states.

In lieu of the fact that many weapons experts consider these developments provocative and destabilizing, the report has already generated considerable controversy. "It is basically a shallow treatment," says an aide to Senator William Proxmire (D-Wis.), who cosponsored the study requirement as an amendment to last year's defense bill. "This is a serious business and to have the Pentagon just come back and manipulate it to justify their nuclear weapons modernization, the "Star Wars" program, and their arms control position is just not serious." Similarly, Jacob Scherr, an attorney who directs a "nuclear winter" study project at the Natural Resources Defense Council, termed it "totally deficient—17 pages of promotion."

Cornell astronomer Carl Sagan, who published an equally controversial assessment of the policy implications of "nuclear winter" in *Foreign Affairs*, says that "we heard from some quarters at the beginning that 'nuclear winter' was liberal propaganda. I'm glad to see that the Pentagon at least acknowledges its possibility. But it is sad that they can grasp the enormous dangers of nuclear war and somehow not realize that the answer is not to build more weapons." Sagan's own prescription is to reduce the total yield of U.S. and Soviet arsenals below a threshold at which "nuclear winter" might be triggered, a level perhaps one-tenth the present total. The Defense Department report, echoing the view taken by most academic experts on "nuclear winter," suggests that no such threshold may exist, and that in any event it cannot be identified at present.

Theodore Postol wonders if soot will incapacitate "Star Wars" defenses.

Much of the criticism is directed at the report's abbreviated treatment of what many analysts have considered the most far-reaching potential military implications of "nuclear winter." These include the possibility that a major war might wreak sufficient environmental havoc to incapacitate key items of military equipment, such as satellites or airborne command posts; that it might render useless any civil defense preparations; and that it might turn a so-called first strike into a suicidal act, through worldwide dispersal of dust, soot, toxic gases, and fallout. "We hear this talk from the Pentagon about a protracted nuclear war, which would supposedly last as long as six months," Proxmire noted last year. "The personnel left to fight a protracted nuclear war might face subfreezing temperatures for months, a devastated agriculture and environment, and global epidemics. Would we have any people to fight a protracted nuclear war even if the equipment worked?"

The report has been criticized because it contains little substantive discussion of such practical considerations. With regard to the effects of soot and dust on key military assets, for example, the report says only that under the Reagan Administration's strategic modernization program, the survivability and effectiveness of command, control, communications, and intelligence devices has been "significantly enhanced." The climatic impact of a first-strike is not even discussed, and the potential implications for civil defense are scarcely mentioned. "The Federal Emergency Management Agency (FEMA) believes that until scientific knowledge regarding climatic impacts of nuclear conflicts is more fully developed it would be impractical to develop cost-effective policies regarding civil defense, or to change existing policies," the report says. [To some extent, the issue may be unimportant: The Administration has proposed a 34 percent cut in FEMA's budget for next year in the wake of several contracting and management scandals.]

The study also did not directly address a host of additional policy issues raised by various weapons experts. Writing in the spring 1984 issue of *Foreign Affairs*, for example, political scientists Dan Horowitz and Robert Lieber noted that nuclear deterrence of Soviet forces in Europe could become somewhat less credible, due to the high density of urban centers there and the danger that any use of nuclear weapons could escalate into a full-scale conflict, triggering a lot of smoky fires and a devastating "nuclear winter." Stanford physicist Theodore Postol has also questioned whether the optically aided antiballistic missile systems and defense radars planned for "Star Wars" can operate in a soot-laden environment.

These issues will doubtless be explored as the new defense budget winds its way through Congress. Senator William Cohen (R-Maine), who co-sponsored the study requirement, has asked for a hearing on "nuclear winter" before the Senate Armed Services Committee.

—R. Jeffrey Smith

March 15, 1985

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

March 18, 1985

Dear Dr. Holmfeld:

This is in response to Congressman Fuqua's letter to Dr. Keyworth of February 25, 1985, concerning additional questions posed by members of the Committee on Science and Technology.

Attached you will find the answers to those questions. If I can be of further assistance do not hesitate to contact my office, (202) 395-7347.

Best regards,

Barbara J. Diering
Barbara J. Diering
Special Assistant to the
Executive Director

Enclosures

Dr. John Holmfeld
Science Consultant
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Technology
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NUCLEAR WINTER

QUESTION: The U.S. Government is accelerating a multi-agency program aimed at assessing the "nuclear winter" hypothesis. Our understanding is that FY 1986 funding will be approximately $5.5 million, with program management residing at OSTP.

a. Why was OSTP chosen as manager of the nuclear winter research programs?

b. What experience does OSTP have in management of large multi-agency, multi-disciplinary research programs?

c. What will be the role of the Department of Defense with respect to program funding and management?

d. Why was the decision made not to place management of the program with NOAA, which has considerable, on-going experience in managing interagency scientific programs (i.e., National Ocean Pollution Program; National Climate Program; National Acid Precipitation Assessment Program)?

ANSWER: The Program management and management of funds to support the various research projects will remain with the respective agencies. There will be a coordinating committee, made up of the participating agencies with OSTP as the chair, as an advisory body to facilitate the flow of information between the agencies and to recommend research. This coordinating committee will be the focal point for communicating with interested parties outside the participating agencies.

THE ATLANTIC MONTHLY

FILE

If the "nuclear winter" theory is correct, an aggressor would destroy himself, even if there were no retaliation

NUCLEAR WINTER AND NUCLEAR STRATEGY

BY THOMAS POWERS

DURING THE OPENING campaigns of the air war against Germany, it didn't take long for the British Bomber Command to realize that the right way to destroy a city is not to break it up with high explosives but to burn it. High-explosive (HE) bombs are purely local affairs. You've got to cube the blast power of the bomb in order to square the area destroyed. Not even a thousand British Lancaster and Halifax bombers, which was the size of the biggest of the fleets raiding Germany by the third year of the war, could carry enough high-explosive bombs to do more than sprinkle cities with holes of destruction. Bomb raids involving HE bombs were terrifying to live through but not very dangerous; casualties were generally few.

But fire is a living thing. Fire consumes and spreads. Fire attacks anything of organic origin the way disease attacks human bodies, and just as epidemics can flash through the crowds of cities, so fire finds a congenial host in the accumulated combustibles—the wood, the paper, and the fabric of cities. In March of 1942 Bomber Command attacked the medieval German city of Lübeck, figuring that its narrow streets of ancient timbered houses meant it would burn well. It did. As the war progressed, the British abandoned daylight attacks on specific industrial targets because too many planes were being shot down and it was too hard to drop bombs accurately. The price was high, the results paltry. So Bomber Command switched to nighttime raids on the sprawling industrial suburbs of German manufacturing centers. Darkness protected the bombers, cities were big enough to find at night, and their size meant that even a miss—and most bombs fell miles wide of the "target"—was still bound to hit *something*. The adoption of the "bomber stream" helped to concentrate the attack. The bombs were fused to explode not on impact but an instant later, which helped to break up buildings. The bomb-load mix was changed as well. A third of each plane's cargo was devoted to HE bombs, which broke windows, blew open doors, and splintered wood into matchsticks. The rest of the load consisted of incendiary bombs to set the wreckage afire.

But the art of burning cities did not approach full flower until July of 1943, when successive raids on Hamburg brought something new into the world—the firestorm. The worst damage occurred on the night of July 27–28, when nearly 750 British bombers dropped 2,326 tons of bombs, about half of them incendiaries. For some reason the bomb patterns were unusually tight that night. A vast fire was ignited, producing temperatures estimated at nearly 1,000° centigrade at the center of the conflagration. Hurricane-force winds roared in from all sides to feed the fire. People abroad in the streets were actually sucked into the fire. Others were mired in molten asphalt, or they melted outside the steel blast doors of bunkers where they had—too late—sought refuge. When survivors inside opened the doors to emerge after the raid, they found pools of fat on the ground. In other shelters the heat was so intense that people were baked brown, leaving shriveled corpses the size of children, or they died of asphyxiation because the firestorm had sucked the air out of the shelter. A study by the United States Strategic Bombing Survey after the war found that the average number of deaths in an ordinary bombing run on an urban area was 1,850. In Hamburg the death toll was over 40,000. Whether this raid helped to win the war

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Thomas Powers is a contributing editor of The Atlantic.

ILLUSTRATIONS BY WENDELL MINOR

is hard to say. One reason for the attack on Hamburg was its importance as a submarine-building center. Some 400 U-boats were launched by the Hamburg yards during the war, about half before the raid and half after. But the Hamburg raid unnerved the German High Command and convinced Allied strategic-bombing enthusiasts that they had found the key to defeat of an enemy from the air.

As things turned out, creating a firestorm was no easy matter; everything had to work just so. But Bomber Command destroyed Dresden with another in February of 1945, and the Americans under General Curtis LeMay succeeded in creating the biggest of all in Tokyo the next month, when a roaring inferno destroyed sixteen square miles of the city and killed more than 80,000 people. In the late spring of 1945 General H. A. "Hap" Arnold asked LeMay how long he thought the war against Japan would last. LeMay said, "Give me thirty minutes." Then he called in one of his operations officers and did the numbers: so many Japanese cities left to burn, so many planes available to fly, so many flying days to do the job. When there were no more cities to burn, the war would be over. LeMay told Arnold, "The first of September." What was new about Hiroshima was not the firestorm—something well understood by that time—but the fact that its infernal horrors had been achieved by one bomb from one plane. This represented a quantum jump in military efficiency. When LeMay saw the Hiroshima photos a few days later, he told me recently, he realized that "we really had something extraordinary."

Burning cities were one enduring image to come out of the war. It obsessed military men for twenty years, but the general public caught the drift as well. I've often thought that this image had a lot to do with the rapid growth of the suburbs surrounding American cities in the 1950s. The message of Coventry, Hamburg, Berlin, Tokyo, and Hiroshima was hard to miss: War destroys cities. *Get out of the cities*. But my notion is a hard one to prove. Perhaps the growth of suburbia was only the doing of the automobile, or of cheap mortgages.

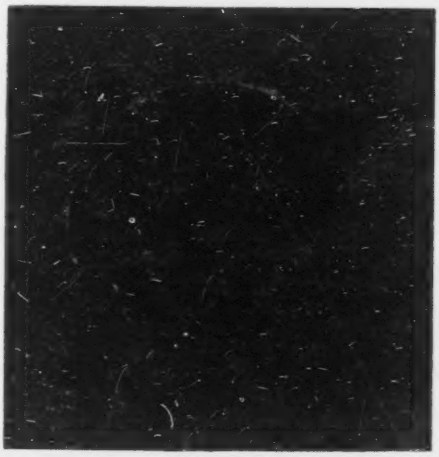
WHAT IS INTERESTING NOW IS SOMETHING THAT was noticed only as a curiosity then—the vast pillars of smoke that rose over the burning cities and then diffused downwind, creating gorgeous sunsets for days thereafter. Color in the evening sky is a function of slanting sunlight shining through stuff in the air—clouds, dust, volcanic ash, the characteristic smoke and fumes of cities. In Cairo once, a friend and I watched the sun set over the Western Desert after a dust storm. The sky was stupendously aflame. On another occasion I took an air taxi down the length of Long Island toward New York City and watched the sun set through the yellow and purple and violet streaks of gunk suspended over the city. It seemed hard to believe that living creatures could breathe that livid stew. A lot of what we think of as nature is really the doing of man. One of the arguments raised against a plan to hide MX missiles among thousands of shelters in the deserts of Nevada and Utah was the dust that construction would stir up—thick enough at the Grand Canyon, hundreds of miles away, scientists said, that tourists often wouldn't be able to see one rim of the canyon from the other.

The general phenomenon is well known. Volcanoes pumping ash into the air can add a streak of color to sunsets thousands of miles away. In 1950 a gigantic fire burned over an area of 10,000 square kilometers of forest in Alberta, Canada. The trees, mostly conifers, were rich in tars and resins, which make oily black smoke. The pall covered about half the land area of the United States, spread across the Atlantic, was detected over Great Britain by aircraft as high as 35,000 feet, and actually reduced the amount of visible light reaching the ground in Western Europe. Smoke hangs well in the air, especially dark, sooty smoke. The particles are small. They absorb sunlight and heat up the surrounding air, which tends to linger aloft in a thick layer. Second World War bombers frequently returned to their bases covered with black soot picked up at altitudes of 20,000 or 30,000 feet. The smoke from the firestorm at Hiroshima, which burned five square miles of the city, was pushed high into the troposphere by the combined heat of the fires and the bomb's fireball. Survivors spoke of the awful darkness and the chill in the August air which accompanied the murk and the gloom. Water vapor condensed and fell back to earth as rain, black with the soot it picked up on the way down. A Japanese novelist, Masuji Ibuse, later wrote a fine novel called *Black Rain* about the bombing of Hiroshima. For him the black rain symbolized the ghastliness of what happened.

But to American officials and scientists who studied the bombing after the war, the black rain—an unexpected effect of the unique explosion—was nothing more than a curiosity. Scores of individuals contributed reports for the U.S. Strategic Bombing Survey account of the attacks on Hiroshima and Nagasaki, but the author of the account, Philip J. Farley, remembers no mention of smoke in the documents he collected. "I thought of the cloud in terms of the scenic effects," Farley said recently in his office at Stanford University, where he now teaches after a long government career spent mostly in the State Department. "Nobody was thinking [of side effects] except in terms of radiation."

Paul Nitze, one of the Survey's two vice-chairmen, took Farley to Japan in August to work on the Survey's study of the Pacific half of the war, and then, in November, assigned him to write the account of Hiroshima and Nagasaki. Farley never visited either city, but the reports he saw covered everything imaginable—heat and blast effects, radiation sickness, the durability of various types of construction, the hopeless task that had faced the city's fire-fighting services, and the like—except the smoke. The limits of the fire were mapped in great detail, but smoke was smoke. How much, where it went, how long it lingered in the air—none of that seemed to matter.

But now the question of smoke is very much on the minds of scientists and military men, for the simple reason that nuclear war would mean large numbers of burning cities, all pumping vast quantities of smoke into the air. Last December five scientists published a paper in *Science* magazine claiming that smoke from as few as a thousand fires in a hundred major cities could cast a sooty pall over the Northern Hemisphere thick and lingering enough to bring darkness at noon and radically cool the earth's surface for months, thereby triggering a climatic catastrophe—a "nuclear winter"—that would threaten many plant and animal species, including man, with extinction. The invention of nuclear weapons has brought dire warnings aplenty in the past few decades, but this one is on an altogether different scale. It's one thing to say that the United States and the Soviet Union would suffer beyond precedent in a nuclear war, even that a nuclear war "would destroy civilization as we know it." It's our civilization, after all; we built it, and perhaps that gives us the right to destroy it. But we are not our own fathers; we did not create the human race, much less the other forms of life that share the planet with us. A defense policy that threatens life itself on such a scale is simply too crazy to stand.



In [illegible]se, the bad news about nuclear winter is *so* bad that it might even be taken as grounds for a perverse optimism. If we finally admit that we can't fight a nuclear war without destroying ourselves—*really* destroying ourselves—then perhaps the time has come to quit preparing to fight one. Even deterrence—preventing war through fear of the consequences—demands a credible threat. Can it be credible to threaten attacks on Soviet cities that would expose both nations—even without Soviet retaliation—to nuclear winter? Thus the problem of burning cities has introduced a wild card into the calculations of American (and presumably of Soviet) war planners.

Of course, many technical uncertainties remain. The authors of the nuclear-winter paper stopped short of claiming to know that a nuclear war would shroud the earth in a long, freezing night and kill everybody. Much scientific work remains to be done. But the preliminary findings are not encouraging; the prospect of smoke from hundreds of burning cities poses a real problem for defense planners. Even military men, normally skeptical of apocalyptic claims, are worried—especially the ones who draw up the plans for targeting nuclear weapons in the event of war. Some of the ones I've talked to—a retired admiral, for example, who was in charge of war planning for the Joint Chiefs of Staff (JCS) in the early 1970s—look rueful, smile ironically, and give vague waves of the hand and shakes of the head when they respond to claims that a thousand large fires in a hundred major cities could mean big trouble worldwide. The targeting experts know we're planning to do worse than that to the Russians. But if you take the cities out of the war plan, there's no plan left. It's an either/or proposition: either we stick to the plan and court ecological catastrophe, or we get rid of the plan and try to think of something else to do with the 9,500 strategic nuclear warheads in the American arsenal. What that might be is hard to imagine. Nuclear weapons are good for igniting fires over hundreds of square kilometers and obliterating downtowns. If cities are off limits, there's not much to use the weapons on. The public is having a hard time trying to grasp just how uncompromising the choice is, but the war planners got the point right away: if the smoke of burning cities is really a problem, then our current plans for fighting a nuclear war amount to literal suicide for the country that strikes first, even if there is no retaliation.

In the popular mind, at least, nuclear war has always meant the end of the world. Numerous public-opinion surveys have shown that the average American *expects* to die if there is a nuclear war; many even hope that they will die. Until recently military officials, and probably most scientists who take an interest in nuclear strategy, have not shared these apocalyptic fears. Indeed, one badge of the weapons fraternity has been a hardheaded knowledge of how bad nuclear war isn't. But ordinary citizens are difficult to reassure. They're convinced that we passed the point of overkill long ago, not just in rhetoric but in fact. Perhaps the toughest thing for the public to understand is why the military wants more nuclear weapons when "we've already got more than we need to kill everybody ten times over." Anyone who writes or speaks professionally about these matters hears this question again and again. The answer is that the world's nuclear arsenal of perhaps 50,000 weapons would certainly be big enough to kill everybody if people would gather together conveniently in exposed places, but not otherwise—or so the experts have thought. To "blow up the world" in the popular sense of the phrase would take far more nuclear weapons than we've got, probably even more than we could make. "There's just not enough fissionable material," Richard Turco, a scientist specializing in atmospheric studies at R & D Associates, in Marina del Rey, California, told me recently. Turco has been studying the effects of nuclear weapons on the atmosphere for years, and he was one of the five authors of the nuclear-winter paper—the phrase is Turco's coinage—published last December. Turco believes that a nuclear war could threaten man and many of his fellow creatures with utter disaster, but, like most technically minded men, he hates imprecision, and he is particularly irritated by popular fears that imagine disaster of the wrong sort. He once did some calculations to see what it would take to blow down all the world's buildings with blast waves, to ignite all the combustible materials on the surface of the earth with thermal pulse, or to expose everyone on earth to a dose of a thousand rads (units of radiation) within an eighteen-hour period. The first two would take about two million megatons of explosive power (that is, the equivalent of two trillion tons of TNT) and the third about a quarter of that amount. "Blowing up the world" in the literal sense is beyond us.

But there is more than one way to skin a cat. The late Herman Kahn, who made his reputation with a huge tome, published in 1960, titled *On Thermonuclear War*, speculated in that book on the feasibility of an ultimate deterrent, a "doomsday machine" that could destroy the planet in the event that the side in control of the trigger felt that it had been pushed into an untenable corner. Kahn could be something of an intellectual rascal; it amused him to carry rationality to extremes, outraging the tenderer hearts of traditional humanists. But also he had a serious purpose in mind. He felt that atomic weapons were a fact of modern life, and had to be considered rationally; they weren't something just to be brandished with wild threats of an apocalyptic *or else*. Kahn put the war plans of the late 1950s into that category. These plans were hard to execute but simple in theory—obliteration of the Soviet Union. In 1953 the Joint Chiefs of Staff approved a plan named Offtackle, devised by the Strategic Air Command (SAC) under LeMay, which called for opening with attacks on Moscow (twenty bombs) and Leningrad (twelve) and then delivering the rest of the arsenal (about 900 weapons in all) to targets in other Soviet and East European cities. Another plan, named Reaper, adopted the following year, called for dropping 1,500 bombs on Soviet targets. Kahn thought this all-or-nothing approach was crazy, and he attacked it obliquely with his doomsday speculations.

The idea behind Kahn's proposal for a doomsday machine, dreamed up pretty much off the top of his head, was simple: pack the deepest hole that could be dug or found with thousands of megatons of nuclear weapons, thereby threatening to shatter the crust of the earth and literally break the planet apart. He concluded that such a project was feasible but dumb. It might blow up the world, all right, but it wouldn't deter, because the other side wouldn't believe anyone was crazy enough to trigger the machine. In a footnote, interestingly, Kahn wondered if we might not create a doomsday machine inadvertently. He decided not: the planet was too tough; you couldn't kill it without really trying.

Kahn worked for the Rand Corporation in 1960; he had high-level security clearances and was privy to a broad range of the nation's nuclear secrets. But like everyone else at the time, he failed to sense the ecological fragility of the earth; he overlooked the potential importance of the humblest of the side effects of nuclear war—the smoke of burning cities; and it never occurred to him that the United States had already built a doomsday machine and had been preparing since the approval of Reaper, in 1954, to use that machine, in complete ignorance of the possible result.

THE THREAT TO THE WORLD'S CLIMATE THAT THE smoke of burning cities poses was a long time sinking in. It was like Edgar Allan Poe's "Purloined Letter"—hidden in plain sight. One strand of discovery goes back to a 1980 theory that the mass extinctions of dinosaur species at the boundary of the Cretaceous and Tertiary periods, about 65 million years ago, were the doing of a large asteroid, perhaps six or seven miles in diameter, which slammed into the earth with tremendous impact. The dust and debris blown up into the atmosphere by the collision would have darkened the sky for months, cooling the surface of the earth and reducing ambient light—that is, the average visible light at the surface of the earth—below the level at which photosynthesis could keep green things alive. Each of these effects was lethal in its own right, but coming together they precipitated a downward spiral—a kind of unraveling of life systems a bit like an economic crash, in which the failure of one business or industry immediately threatens another, until all lie in ruins. The dinosaur-extinction theory was substantially revised over the following few years, but one point was established pretty thoroughly—junk in the upper atmosphere could have a significant darkening and cooling effect on the earth's surface.

A second strand of discovery began in 1971, when the *Mariner 9* space probe went into orbit around Mars and began transmitting photographs of the planet entirely surrounded by dust from a vast Martian storm. Carl Sagan, the well-known Cornell University astronomer, and other scientists monitoring the probe spent three months studying Martian dust storms, because there was nothing much else to do while they waited for the Martian atmosphere to clear. One thing they learned was that dust in the upper atmosphere tends to absorb sunlight and heat up, while the surface of the planet, in semidarkness, tends to cool down. The models they devised to describe the behavior of Martian dust storms seem to work equally well for the effects of volcanic eruptions on Earth.

The biggest of these, according to a study by the Smithsonian Institution, occurred in April of 1815, on the island of Sumbawa, in the Indonesian archipelago. Days of earth tremors and mighty rumbling like the sound of cannon culminated in a single tremendous explosion that blew off the top 4,200 feet of Mount Tambora and cast up some twenty-five cubic miles of earth and rock into the atmosphere—roughly a hundred times the stuff spewed up by Mount St. Helens or by the eruption of Vesuvius, which buried Herculaneum and Pompeii in A.D. 79. So dense was the dust, smoke, and ash in the air that the Tambora eruption was followed by three days of total darkness over an area 400 miles across. The volcano's plume carried debris into the stratosphere—the cold, rainless, slowly swirling blanket of thin air above the troposphere—where it circled the earth for a year or two before settling out. Scientists have estimated that the dust cloud generated by Tambora resulted in a cooling of the earth's surface that averaged about sixth tenths of one degree centigrade. That may not sound like much, but the result in New England has been remembered ever since as "the year there was no summer." Killing frosts in every month of the year in northern New England, and cold throughout the region, severely damaged crops and led to wheat prices so high that they weren't equaled for more than 150 years, until 1972. Similar weather in Europe caused outright famine in many areas, probably triggered a typhus epidemic that spread from Ireland to England, and may have contributed in a roundabout way to the arrival of cholera in Europe in the 1830s.

Another strand of discovery emerged in the early 1970s, when scientists demonstrated that the fluorocarbons used to provide the pressure in aerosol cans of everything from shaving cream to oven cleaner and deodorant could break down ozone. Ozone is only a minor component of the earth's atmosphere, but it is nevertheless important. A belt of the gas surrounds the planet and shields it from a good part of the sun's ultraviolet rays, mild doses of which cause sunburn, and strong, direct doses of which can cause skin cancer and blindness. The fluorocarbon controversy, typically, resulted in a broad range of scientific studies demonstrating that fluorocarbons do indeed drift into the upper atmosphere, where they break down ozone. Whether pressurized aerosol cans could release enough fluorocarbons to endanger the ozone layer was never conclusively established, but the controversy directed attention to another problem—the tendency of nuclear detonations in the megaton range to produce large quantities of nitrous oxides and to carry them up into the stratosphere, where, like fluorocarbons, they break down ozone. In 1975 the National Academy of Sciences published a major study titled ***Long-term Worldwide Effects of Multiple Nuclear-Weapon Detonations***, which concluded that a major nuclear war would deplete the ozone layer, that this would increase the amount of ultraviolet light reaching the surface of the earth to a serious but not catastrophic degree, and that this effect would persist for several years before the ozone layer replenished itself naturally.

THROUGHOUT THE 1970s the pieces were coming together: the controversy over dinosaur extinctions, the Martian-dust-storm studies, climatologists' increasingly sophisticated understanding of the effects of volcanic eruptions on weather, and the work by the National Academy of Sciences on ozone depletion prepared the way for illumination of the biggest light bulb of all—the realization that smoke, if there were enough of it, and if it reached high enough, had the capacity to plunge the globe into freezing darkness.

The first serious study of the smoke that would be generated by nuclear warfare, by Paul Crutzen, a West German scientist, and John Birks, an American, was published in a special issue of ***Ambio***, the journal of Sweden's Royal Academy of Sciences, in June of 1982. Crutzen and Birks assumed that a major nuclear war would ignite about five percent of the 20 million square kilometers of forest in the world's temperate regions. Their calculations showed that the smoke from these vast fires, like the dust generated by volcanic eruptions, but on a much greater scale, would threaten the climate through heating of the upper atmosphere and cooling of the earth's surface.

An early preprint of the ***Ambio*** article circulated among scientists at a meeting in Santa Barbara, California, in early 1982, where Richard Turco, who had worked on the ozone problem, read it. He started to crunch numbers on his own to see what would happen. Eventually he and four other scientists—Brian Toon, Thomas Ackerman, James Pollack, and Carl Sagan—wrote a detailed, 127-page scientific paper called the Blue Book (the group were also the authors of the article published in *Science* last December; this was basically a condensed and corrected version of the

Blue Book), and this was reviewed in detail by about a hundred scientists at a four-day meeting held in Cambridge, Massachusetts, in April of 1983. The Blue Book estimated the ozone and radiation effects of nuclear war along with the smoke problem, and went another step beyond the Crutzen and Birks study by accounting for the smoke from burning cities—a threat to the earth's climate much greater than forest fires, because there is more to burn in cities, and because the nature of the fires would help push smoke high into the atmosphere. By this time the nuclear-winter thesis was a subject of wide discussion throughout military and scientific circles in the United States. Technical objections were numerous, and every aspect of the paper's data base, methodology, climate modeling, and results was scrutinized rigorously at the Cambridge meeting. The TTAPS authors (the acronym is formed from the initials of their last names, and is pronounced as if there were only one T) were the first to admit that their work contained numerous uncertainties, but their science held up with sufficient "robustness" (scientific argot meaning that an answer to a question tends to come out the same even if you fiddle with the assumptions) to make any sober investigator recognize that this problem could not be lightly dismissed.

Available only in mimeographed form, the Blue Book makes hard reading for a layman. It is filled with the names of unfamiliar chemical compounds like peroxyacetyl nitrate, hard-to-imagine numbers like 10^9, numerous technical terms like ***entrainment*** and ***hygroscopic***, and mathematical symbols like $\sim$, $<$, $>$, ℓ and $\leq$. There are seventeen graphs, some of which have more ups and downs than a comb has teeth, and eighteen pages of references to more than 200 published scientific studies, which start with Aandahl, A.R., *Soils of the Great Plains*, and wind up with Yokoyama, I., "A Geophysical Interpretation of the 1883 Krakatoa Eruption." The Blue Book's authors studied several dozen imaginary nuclear wars, ranging from an all-out, 25,000-megaton exchange of the sort Herman Kahn used to refer to as a "spasm war," down to a relatively small (and improbable, as we shall see), 100-megaton war involving a thousand detonations entirely on cities. Keeping these wars straight as one reads is no easy task. The Blue Book frankly confesses, "The overall uncertainty in the present calculations is quite large. It arises from a lack of knowledge of the number, yields and types of nuclear bursts which might be detonated in a war, of the basic physical properties of nuclear dust and smoke, of the causes and characteristics of mass nuclear fires in cities and forests, and of the response of the atmosphere to enormous particle injections."

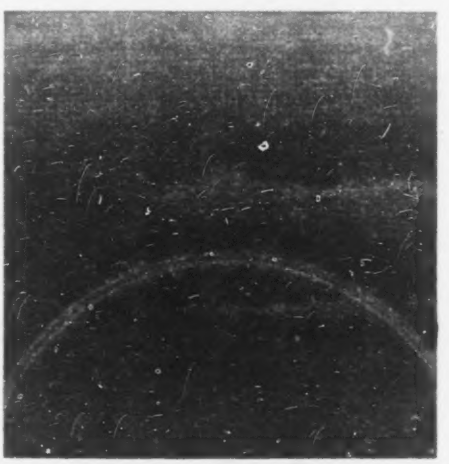
Nevertheless, few readers would have difficulty in grasping the disquieting central message of the Blue Book. Nuclear weapons, especially when detonated in the air, produce an intense thermal pulse that can ignite fires simultaneously over vast areas. Any city attacked with nuclear weapons will burn, and many of these burning cities will generate firestorms whose gigantic smoke columns will carry soot particles into the upper atmosphere, where they might linger for months before settling out. The pall of smoke from burning cities would rapidly diffuse over the mid-latitudes of the Northern Hemisphere and might circulate into the tropical regions around the equator, which, for complex reasons, would be even more sensitive to changes in ambient light and temperature. Darkness at the earth's surface would bring a decline in mean annual temperatures of as much as 40° centigrade for months. If the war took place in spring or early summer, temperatures might fall well below zero throughout July, August, and September. For months it might be as dark at midday as it normally is on a moonlit night. The effects of this long, cold "night" on plant ecology—and everything that lives is ultimately dependent on the photosynthesis of plants—are hard to predict in detail but would almost certainly be catastrophic.

The science in the Blue Book may be complex, but it describes a simple mechanism. Think of the relief that comes on a hot, clear day in July when you pass from the brutal glare of the midday sun to the deep shade of a maple tree, or even a beach umbrella. Under normal conditions the heat absorbed from sunlight during the day escapes at night—but slowly, because the earth's atmosphere serves as a kind of blanket. The longer the night, the more heat escapes. In a "night" lasting months, heat would go on escaping and temperatures would go on dropping. In trying to calculate the smoke effects of a nuclear war, the first and most important question is: How many fires would be ignited? The answer is a military secret. It is contained in the war plans for targeting nuclear weapons which have been drawn up by military men in the United States and the Soviet Union.

THE EARLIEST AND THE MOST PERSISTENT CRITICISMS of the nuclear-winter thesis have focused on scenarios—imaginary nuclear wars devised as a tool for predicting effects. When Richard Turco briefed his colleagues at R & D Associates on an early version of the Blue Book, some of them were quick to point out that he was trying to calculate the effects of wars that would never happen. One scenario, for example, describes a 100-megaton war in which 1,000 warheads of 100 kilotons each are detonated over 1,000 urban targets. Such a war would certainly produce a lot of smoke, but it is not anything we have to worry about. It contradicts too many principles of nuclear strategy, which call for wars of extreme caution or reckless extravagance—nothing in between. If American war planners elected to "limit" a war to 100 megatons, they would stay away from cities, which are generally targeted only in the final, all-out phases of war plans. If the planners decided to hit 1,000 urban targets (an attack virtually certain to bring an all-out response), they would use a lot more than 100 megatons and would target a lot of other things as well.

Academic defense analysts have often faulted the

TTAPS study for worrying about the wrong sorts of wars, but the Pentagon has not joined them. When the TTAPS group presented its findings at a highly publicized conference in Washington, a year ago October, the response from the White House and the Pentagon was virtual silence. Many skeptical outsiders (including me, at first) interpreted this silence as indifference, as just one more bit of evidence, if any were needed, that the military was narrowly focused on its own obsessions—what the Russians had, and what we had that could destroy what the Russians had. But in fact something deeper was at work. In early December the assistant secretary of Defense for atomic energy, Richard Wagner, arranged for a briefing of Pentagon officials on the nuclear-winter findings. One of those who took part was Michael May, a former director of the Lawrence Livermore National Laboratory, which, like Los Alamos, is mainly concerned with the design and development of nuclear weapons. May, who is still active at the Livermore Lab, and his colleagues—especially Michael MacCracken, an expert on climate—had already studied the nuclear-winter thesis in detail, and they told the assembled Pentagon officials that the problem was a serious one. Although they disagreed with some of the assumptions, they found no obvious faults in the science. The smoke of burning cities posed a serious threat to the earth's climate.



May has spent most of his life in weapons work. The Livermore Lab, founded largely through the efforts of Edward Teller, specialized early in advanced warheads and has designed perhaps half of those in the current American arsenal. The people who work at Livermore believe in deterrence, believe in making good weapons better, and believe that much public criticism of their work is based on misinformation and hysteria. If the nuclear-winter thesis had been full of holes, May and his colleagues would not have hesitated to say so. The briefing—which was gloomy not only from a broadly human but also from a narrow military point of view—resulted in the Pentagon's public silence and its private support for further research. The reason was simple: the nuclear-winter thesis, if valid, threatens to make nonsense of every notion the planners have managed to come up with, in forty years of trying to devise a sensible way to fight a nuclear war.

Theories of how to fight a nuclear war come in two styles—one that is abstract and analytical, often referred to by professionals as metaphysics or theology, and another that is severely concrete and practical, called war planning. Most of what the public knows about these matters comes from listening in on the debates of theologians, who construct elaborate chains of "if–then" reasoning—if the enemy does X, then we do Y. The theologians are mainly concerned with demonstrating that nuclear weapons are safe to have, because they are too dangerous to use. Nuclear theology is a cottage industry providing gainful employment to many hundreds of academic defense specialists. A cynic might be forgiven for concluding that the Pentagon is willing to pay for so much theology to maintain a kind of smokescreen, behind which the real work is conducted by the war planners—the middle-ranking officers, mostly in the Air Force, who are responsible for the nuts-and-bolts details of running a nuclear war.

War planning is a very different sort of enterprise. Theologians talk about "an opponent" or "the enemy." War planners talk about the Russians. The planners begin with a courtly bow to deterrence—if we're ready, it won't happen—but that's the end of it. All the rest is deciding what to shoot at and when to shoot at it. The fundamental thing to grasp about war planning is that we *plan* to do what we *can* do.

For the past forty years the American nuclear arsenal has been in constant flux, becoming steadily more lethal through increases in the number of weapons, greater versatility in firing and retargeting, and improved accuracy. In the early plans weapons were targeted on the center of Moscow; now they might be targeted on the Ministry of Foreign Affairs, or on the main entrance to a blast shelter intended for top officials of GOSPLAN, the central Soviet economic-planning office, or on a point calculated to include three or more targets—say, a truck plant, a power station, and a local office of the KGB—within the lethal radius of a single warhead. As the weapons grow more numerous, the targets tend to divide, and the number of aiming points, or desired ground zeros (DGZs), always seems to be a jump ahead of the weapons available to attack them. Consider, for example, the problem facing planners who hope to cripple Soviet rail transport. With only a few weapons available for the task, they would limit targets to major switching yards. Given more weapons, the planners would add locomotive production plants and repair facilities to the list of targets. Eventually, with a big inventory of weapons available, minor bridges, rural sidings, telegraph offices, steel-rolling mills for the production of rails, and the central pension office for retired rail workers might all be included in the plan. The Harvard biochemist Paul Doty, long active as a consultant on defense issues, once asked the planners what was the smallest target on the list. The answer was an open field that might be used as a landing strip by returning Soviet bombers.

The dominant tone of the military mind is cautious. War may be hell, as General William Tecumseh Sherman characterized it, after cutting a swath of destruction through the South during the Civil War, but for the men who prepare to fight wars there is something worse than the horrors of battle: losing. From their point of view, too much is barely enough. Thus American planning for nuclear war—and no doubt Soviet planning as well—has always relied on overkill, an attempt to achieve certainty of result through overwhelming strength. General LeMay's theory of war was brutally simple. Back in 1953 he told Sam Cohen, a young defense consultant and weapons designer now best known for his invention of the neutron bomb, "I'll tell you what war is all about—you've got to kill people, and when you've killed enough they stop fighting." LeMay wanted the biggest warheads he could get. Eventually he loaded his planes with 20-megaton bombs, and his staff worked up plans for the virtual annihilation of the Soviet Union. A Navy captain who received a SAC briefing on war plans in early 1954 reported to a superior, "The final impression was that virtually all of Russia would be nothing but a smoking, radiating ruin at the end of two hours."

But it is still hard to say what LeMay's plans called for, because he wouldn't tell anybody—not the White House, not the Joint Chiefs of Staff, and certainly not Sam Cohen, who'd been sent out to SAC headquarters, in Omaha, to find that out, among other things. "This involves our secret war plans," LeMay told him. "I'm not going to tell you what they are." There is even some evidence that LeMay thought it was up to him to decide *when* to go to war.

THE PATH INTO NIGHT

Two drawn out
calls of birds
falling in fifths
in early evening,
and now the tree frogs
start to throb.

If one's whole life
were to be this
solitary would the
true notes
start to sound:
repeated bird song
measuring darkness?

—*Kathleen Spivack*

But for all LeMay's secrecy the war plans were really very simple—hit 'em with everything we have. By 1960 we had a lot. In November of that year President Eisenhower sent a three-man team headed by his science adviser, George Kistiakowsky, to Offutt Air Force Base, in Omaha, to check up on the war plans being devised by the newly established Joint Strategic Target Planning Staff (JSTPS). Eisenhower was afraid that SAC was fiddling with the figures as a way of building pressure for more planes and bombs—for example, insisting that it would take several large nuclear weapons to destroy a hydroelectric dam with 100 percent certainty, when a single small one might do the job with 96 percent certainty. Kistiakowsky was accompanied by two young assistants, George Rathjens, a scientist now teaching at MIT, and Herbert Scoville, a former deputy director for science and technology at the CIA who is now a leading arms-control advocate.

The three men got a royal runaround at SAC headquarters from Air Force briefing officers under instructions to reveal as little as possible as slowly as possible. But they persisted, and eventually got a good idea of what was going into the first Single Integrated Operational Plan (SIOP). They were horrified to discover that the plan would almost entirely ignore the collateral effects of nuclear weapons. With few exceptions, SAC intended to destroy targets by blast pressure alone. If the prevailing winds on D-day were blowing from Leningrad toward Finland, then warheads targeted on the city would be fused to detonate in the air, to avoid the fallout characteristic of ground bursts, but that was about the only concession the JSTPS made to radioactivity. The tendency toward overkill was compounded by establishing a "very high certainty of kill against all these targets," according to Rathjens. That meant using more than one warhead, or warheads with very large yields, or both. The first SIOP, officially approved in December of 1960, called for an all-out attack on Russia with 4,000 weapons fired in "one flush"—everything we had.

THE DETAILS OF THE SIOP HAVE CHANGED A GREAT deal since 1960. The U.S. strategic arsenal now includes twice as many warheads, and many of them are extremely accurate. For our purpose here, one point is of overriding importance: all versions of the SIOP include plans for a society-destroying attack on Soviet "recovery targets"—the Soviet institutions that make Russia strong—and thousands of these targets are in Soviet cities.

We have always insisted that we do not plan to attack Soviet cities or the population per se, but the point is an academic one. Soviet cities are rich in targets—communications and transportation centers, offices of leading institutions of Soviet society like the Communist Party and the KGB, military command posts, blast shelters for the leadership, factories that make war materials, and so on. Even attacks on airfields—a staple of all war plans since the early 1950s—would threaten vast urban areas with fire. A 1978 study by the Arms Control and Disarmament Agency (ACDA) suggests the magnitude of the problem. In order to estimate the effectiveness of Soviet civil-defense planning (a subject of much contention in Washington at the time), ACDA outlined a typical American second strike, to follow a full-fledged Soviet counterforce attack on the United States (the purpose of which would be not destruction pure and simple but the elimination of things identified as the source of military and economic strength). Moscow alone would be struck with about sixty warheads, Leningrad with more than forty, the next eight largest cities with an average of thirteen warheads each. The next forty largest cities would receive an average of 14.4 warheads per million population and the 150 cities after that an average of 25.7 per million; 80 percent of all Soviet cities over 25,000 in population would be struck with nuclear weapons. All of these would burn. The United States could expect to suffer similar damage in return. Such attacks are integral to American theories of how to fight a nuclear war. "There's never been one of those plans that didn't have cities in it," William Kaufmann, a defense expert, says. "I don't care if it's the 1961 SIOP, or the '73 or the '78. The main difference now is that the set of non-urban targets has been expanded." At the Livermore Lab, Michael May said recently that he wasn't sure whether the nuclear-winter thesis would stand up, but that he very much doubted the war planners would be willing to leave cities out of the targeting line-up. "You can say, Don't shoot at the cities—that's fine," he said. "But are they [the Russians] going to leave all our airfields alone and let the B-52s and [midair-refueling] tankers land at them? Think of the aerospace targets in Los Angeles. Are they going to leave those alone even if they have the best of intentions for the Angelenos? It's not hard to come up with five hundred high-priority targets associated with cities, not hard at all."

If those targets are attacked, the cities will burn. If those targets are spared, we have no theory of how to fight a nuclear war. As a result the war planners are now faced with an extraordinary dilemma: either we stick to the theory and plan to run the risk of plunging the Northern Hemisphere into a nuclear winter triggered by the smoke of burning cities, or we abandon the theory and finally admit we simply cannot fight a war with nuclear weapons.

NOT LONG AGO A FRIEND TOLD ME A STORY THAT HE said had been told to him by someone who had heard it from a staff member on Jimmy Carter's National Security Council. It goes like this: When Carter and President-elect Ronald Reagan met after the election in 1980 to discuss the transition, Carter chose to use his time to tell Reagan what "pushing the button" would actually mean. According to the staffer, Carter really laid it out—the numbers of weapons and where they would go, the impossible difficulties involved in trying to keep track of the progress of the war, the excellent chance that the President would find himself aloft in his command plane with nowhere to land and nothing but static coming over the radios. The ghastliness sank in. When Reagan left the meeting, he was ashen and subdued. He finally *knew*.

It's an appealing story. I'm sure we all hope it's true, but it's almost certainly apocryphal. I've heard variants of it many times about other Presidents and high officials. I've come to think of these stories collectively as the Myth of the Frightened President. The drift of the stories is always the same: A man reaches high office, full of insouciant confidence. He gets "the briefing." He comes away sober and shaken. It's as if the collective unconscious of Washington, where these stories are mainly told, needs to be reassured that the men at the top really understand the danger we face.

The evidence suggests that the reality is quite different. With the possible exception of Jimmy Carter, who had an enormous appetite for technical detail, no postwar American President has really understood precisely what we intend to do in the event of nuclear war.

Everything Eisenhower knew about the first SIOP came from George Kistiakowsky's ninety-minute briefing after his trip to Omaha in November of 1960. Four thousand targets in ninety minutes is pretty cursory. President Kennedy was urged to ask for a look at the SIOP early in his Administration, but the JCS discouraged him. They told him it was too technical—routes, refueling schedules, target coordinates, times on target, overlapping E-95 circles, and the like. Lyndon Johnson was bored by nuclear strategy and obsessed by Vietnam. According to people who were there, Richard Nixon's mind wandered when war plans were discussed. Admiral Elmo Zumwalt, the chief of naval operations during the Nixon Administration, describes in his memoirs a National Security Council briefing held shortly after Nixon had signed National Security Decision Memorandum 242, in January of 1974. This was the first of the so-called "war-fighting" documents that have marked a gradual sea change in American nuclear strategy over the past ten years. Before it was signed, the SIOP contained four basic war plans, or options, the smallest of which called for the use of 2,500 warheads. Afterward the JSTPS devised many new options, ranging from the delivery of a "few score" warheads on up to furious salvos intended to annihilate Soviet society—always the last stage of U.S. war plans. Many cities feel that the countervailing strategy adopted in 242 makes nuclear war more likely. Whether they are right is hard to say. But according to Zumwalt, Nixon had no idea what was implied by the new strategy.

Gerald Ford signed a similar document affecting strategy on his last day in office without—according to several National Security Council staffers—any clear idea of what he was doing. Carter was the exception: he drilled himself with frequent command-post exercises and fully grasped the importance of his own strategy document, Presidential Directive 59, which carried the war-fighting approach a step further and dwelt on the need for enhanced command, control, communications, and intelligence facilities to keep track of a war. Ronald Reagan represents a reversion to the traditional presidential approach: leaving the details to aides.

For the first ten years of its existence the JSTPS was pretty much on its own in coming up with a strategy on which to base its war plans. Guidance from the White House and the Pentagon was limited. Richard Garwin, who helped design the first hydrogen bombs and who has long been an adviser to the Air Force on targeting, told me not long ago that the men who picked targets used to read the public speeches of the President and his principal advisers for an idea of how to proceed. Since 1970 the war-planning process has been rationalized. Now it typically begins with a brief presidential document, perhaps ten pages in length—Nixon's was NSDM 242, Carter's was PD 59, Reagan's is National Security Decision Directive 13. With this as a guide the Office of the Secretary of Defense drafts a somewhat longer Nuclear Weapons Employment Policy (NUWEP), which is further elaborated by the office of the JCS and then forwarded to the JSTPS in Omaha for its twice-a-year revision of the SIOP.

When the revised plan is ready, officers from the JSTPS brief the staff of the Joint Chiefs, who brief the Joint Chiefs, who brief the secretary of Defense, who may or may not brief the President—but the extent of the briefing drops off sharply as it rises up through the Pentagon. Ninety minutes seems to be the outside limit at the upper levels. It is highly unlikely that anyone above the Joint Chiefs of Staff level really understands what is in the SIOP. According to many sources, there is no independent review of the SIOP at any stage in the planning process; the size of the U.S. arsenal provides the only limit to the size of a major projected war; and no one involved in drawing up the SIOP is authorized to consider the gross environmental effects of carrying out the plan. As a practical matter, if the nuclear-winter thesis is confirmed, then participation in the war-planning process, at all levels, will have to be broadened, current theories of how to fight a nuclear war will have to be jettisoned, and a whole new generation of weaponry, designed to implement a whole new strategy, will have to be developed and deployed. All of these things would be difficult, but none would be impossible. The military "solution" to the nuclear-winter problem is particularly clear—a much larger number of much smaller, extremely accurate weapons that would allow targets in cities to be destroyed without burning down the cities around them.

A Pentagon planner recently told William Arkin, a Washington journalist and defense specialist, "I wouldn't mind having twenty-five thousand Pershing IIs with forty-kiloton warheads, if they told me I had to have a hundred-megaton force." The nuclear-winter problem does not end the possibility of a big war with Russia, but it does push planners in a new direction, away from apocalypse. Nothing stands in the way of this change except habit, inertia, and the quite staggering cost in money of building a whole new arsenal.

THE OFFICIAL RESPONSE TO THE NUCLEAR-WINTER problem has been reticence in public combined with funding for more study. Just about everybody, including the TTAPS authors, agrees that more study is required. The National Academy of Sciences is sponsoring a major new research effort, and other projects have been started at Livermore and Los Alamos and in the Pentagon's own Defense Nuclear Agency (DNA), which has been commissioning studies on the effects of nuclear weapons for years. The target planners in Omaha use DNA handbooks for estimating collateral damage, for example, but the current work is probably the first that will come up with guidelines for an overall limit—an admission that there is such a thing as a level of damage too great for the planet to handle.

"More study" will serve by way of response for a year or two, but what then? Pentagon officials are plainly worried about the nuclear-winter problem, and plainly at a loss over what to do about it. In conversation with officials at the nuts-and-bolts level one picks up interesting nuances of reaction: a wistful hope that "more study" will make the nuclear-winter problem go away, embarrassment at having overlooked it for nearly forty years, resentment that the peacenik doom-mongers might have been right all these years, even if they didn't know why they were. Above all, one finds frank dismay at what the nuclear-winter problem does to a defense policy heavily based on nuclear weapons. Being only human, officials are probably hoping to turn up uncertainties enough to justify more study forever, or at least until the next Administration. But to me, recognition of the nuclear-winter problem, awful as it is, seems a piece of immense good fortune at the eleventh hour, and a sign that Providence hasn't given up on us yet. □

SCOPE 28

ENVIRONMENTAL CONSEQUENCES OF NUCLEAR WAR

Foreword

and

Executive Summaries

(Vol. I and II)

SCOPE 28

Foreword

Beginning in the summer of 1982, approximately 300 scientists from more than 30 countries and a wide range of disciplines, under the auspices of the International Council of Scientific Unions (ICSU), joined in a deliberative effort to appraise the state of knowledge of the possible environmental consequences of nuclear war. Although it has been recognized since the first nuclear explosions over Hiroshima and Nagasaki in 1945 that multiple detonations could cause massive destruction on people and their culture, the effects of life support systems of air, water, and soil and on organisms received relatively little emphasis in public discussion.

In the mid-1970s, attention began to turn to the whole range of consequences that might be expected to follow a large-scale exchange of nuclear weapons. This reflected a growing recognition of the immense number and yield of thermonuclear devices in the arsenals of the nuclear powers. The renewed activities also reflected concern with effects beyond the direct destruction of cities and human life. While interest still centered on the well-studied issues of direct blast, thermal effects, and radioactive fallout from ground and air bursts, scientists began to consider the large-scale consequences (e.g., from possible global depletion of ozone and from perturbations to the atmosphere). This concern was manifested in studies of information that had accumulated from the detonations at Hiroshima and Nagasaki and the subsequent series of nuclear tests, and with extrapolation of these data to situations in which the current nuclear arsenal might be used. Among the analyses were those by the U.S. Senate Committee on Foreign Relations (1975), the U.S. National Academy of Sciences (1975), the Office of Technology Assessment of the U.S. Congress (1979), the United Nations Environment Programme (1980), the United Nations (1980), and A. Katz (1982).

In 1982, several organizations and individual scientists launched new examinations of anticipated global effects, including those of the American Association for the Advancement of Science, the U.S. National Academy of Sciences, and the World Health Organization. Appraisals commissioned by the Royal Swedish Academy of Sciences published in Ambio in April 1982 were particularly influential. A paper in that issue by P. Crutzen and J. Birks had been intended to deal with possible effects on the stratospheric ozone layer and regional air quality. While it did suggest that ozone changes might be of significance, the new suggestion was that smoke and soot generated by large urban and forest fires might cause reductions in light at the Earth's surface, inducing profound changes in weather. These suggestions stimulated a new round of research and appraisal around the world. Not since the 1960s, when agitation about the consequences of delayed radioactive fallout from bomb tests in the 1950s resulted in the signing in 1963 of the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space, and Under Water, had as much thoughtful attention been marshalled by scientists and citizens.

At its General Assembly in Ottawa in June 1982, the Scientific Committee on Problems of the Environment (SCOPE)—one of the ten Scientific Committees of the International Council of Scientific Unions (ICSU) concluded that "the risk of nuclear warfare overshadows all other hazards to humanity and its habitat" and asked its Executive Committee to consider what further action might be appropriate for SCOPE. In September 1982, the General Assembly of ICSU passed the following resolution:

> *Recognizing* the need for public understanding of the possible consequences of the nuclear arms race and the scientific competence that can be mobilized by ICSU to make an assessment of the biological, medical and physical effects of the large-scale use of nuclear weapons.
>
> *Urges* the Executive Board to appoint a special committee to study these effects and to prepare a report for wide dissemination that would be an unemotional, nonpolitical, authoritative and readily understandable statement of the effects of nuclear war, even a limited one, on human beings and on other parts of the biosphere.

Accordingly, a Steering Committee for the SCOPE-ENUWAR (Environmental Effects of Nuclear War) study was established, with responsibility to initiate the study requested by ICSU and to oversee the selection and recruitment of participants. A SCOPE-ENUWAR coordinating office was established at the University of Essex. From the outset it was agreed that the report would not deal explicitly with questions of public policy, but would focus on scientific knowledge of physical effects and biological response. International aspects of the direct medical effects have already been dealt with explicitly by the World Health Organization, and thus are not taken up in this study.

The SCOPE-ENUWAR process involved the active collaboration of scientists, bringing together the insights and skills of numerous disciplines. Preparatory workshops were held in London and Stockholm, and major workshops were convened in New Delhi, Leningrad, Paris, Hiroshima and Tokyo. Delft, Toronto, Caracas, Melbourne, and finally at the University of Essex in an attempt to arrive at a consensus. Smaller groups gathered in a variety of other places, chiefly in connection with meetings of International Scientific Unions. Meanwhile, new findings were becoming available as noted in appropriate parts of this report, and further studies of likely effects were published (Turco et al., 1983; Ehrlich et al., 1983; Aleksandrov et al., 1983; Openshaw et al., 1983; World Health Organization, 1984; Covey et al., 1984; London and White, 1984; United Nations, 1984; Harwell, 1984; National Research Council, 1985; The Royal Society of Canada, 1985; The Royal Society of New Zealand, 1985).

Support for the project came from individual donations of time and from organizational grants. The Steering Committee is particularly grateful to those who committed the extensive time and effort to prepare the two volumes reporting these important scientific results. Barrie Pittock, Thomas Ackerman, Paul Crutzen, Michael MacCracken, Charles Shapiro, and Richard Turco have been responsible for preparation of the volume on physical and atmospheric effects. Mark Harwell, Thomas Hutchinson, Wendell Cropper, Jr., Christine Harwell and Herbert Grover have played the major role in preparing the volume on ecological and agricultural effects. Both sets of authors were assisted by many colleagues, listed elsewhere in these volumes, who collaborated with them and generously gave of their time to participate in discussion, analysis, writing, and review. It was very much a cooperative, voluntary effort.

The collaboration among these scientists was made possible by financial contributions covering the costs of travel, assistance by post-doctoral fellows, workshop arrangements, and secretarial support. Initial grants making possible the planning of the project came from the SCOPE Executive Committee, using contributions from its 36 member academies of science, and from ICSU. The Royal Society of London hosted the preliminary and concluding workshops and funded the SCOPE-ENUWAR office. Other workshops were hosted by the Royal Swedish Academy of Sciences, the Indian National Science Academy, the Academy of Sciences of the U.S.S.R., la Maison de Chimie of France, the T.N.O. Institute of Applied Geosciences of the Netherlands, the Australian Academy of Science jointly with the Royal Society of New Zealand, the United Nations University and the Venezuelian Institute of Scientific Investigation. Major grants for travel and other expenses were provided by the Carnegie Corporation of New York, The General Service Foundation, The Andrew W. Mellon Foundation, the W. Alton Jones Foundation, and The Rockefeller Brothers Fund.

Recognizing that the issues dealt with in this report transcend science and technology and involve moral and ethical issues, SCOPE-ENUWAR cosponsored an *ad hoc* meeting of scientists and scholars of ethics and morality at the Rockefeller Conference and Study Centre, Bellagio, Italy, in November 1984. The conference took note of the preliminary findings that a significant nuclear exchange could lead to an unprecedented climatic perturbation, killing crops and threatening countries distant from the target areas with mass starvation. A statement called for the development of more effective cooperative efforts for dealing with common interests and problems and urged collaboration between science and religion in the "... quest for a just and peaceful world" (*Bulletin of Atomic Scientists*, April 1985, pp. 49–50).

The Steering Committee has elected to publish the results of the SCOPE-ENUWAR studies in two volumes. The first volume deals with the physical aspects of the environmental impact of a nuclear war. The second volume addresses the biological impacts, principally the ecological and agricultural effects. As further background for the reader, each volume includes the Executive Summary of the companion volume, with its explanation of findings and research recommendations, as an appendix. In addition, the Committee has commissioned a less technical account intended for wide international distribution to fulfill the ICSU request for a "... readily understandable statement of the effects of nuclear war." It is anticipated that this third volume will be translated into several languages.

The two volumes present a general consensus among the scientists concerned with the study. There is not unanimity on all points, but a concentrated effort has been made to describe those remaining points at issue. These unresolved issues suggest research that should be pursued in order to reduce the present degree of uncertainty. The report should be regarded as the first attempt by an international scientific group to bring together what is known, and what must still be learned, about the possible global environmental effects of nuclear war. It should not be the last. It should be taken as a point of departure rather than as a completed investigation.

A recurring issue in the recent discussion of the long-term, global environmental consequences of a nuclear war has been the degree to which uncertainties preclude a conclusion regarding the plausibility of severe effects. These uncertainties are of two kinds: (1) those resulting from the nature of human actions (e.g., number of weapons, yields, targets, height of detonation, time of conflict, accidents resulting from technological failure, societal response to an outbreak of hostilities): and (2) those resulting from an incomplete state of knowledge concerning physical and biological processes and the limited ability to simulate them faithfully by mathematical models.

Clearly, the specific circumstances of a large-scale nuclear war cannot be predicted with confidence, and the history of past wars reminds us that even carefully planned military actions rarely develop as expected. Thus, detailed scenarios of possible nuclear exchanges must remain highly speculative. Wherever practicable, as a basis for estimating environmental effects, the report considers specific ranges of physical parameters and responses—such as a given mass of smoke injected into the atmosphere, or the occurrence of a freezing episode—that are consistent with the detailed technical analyses, yet are not peculiar to any specific war scenario. In the absence of a nuclear war, many of the specific effects will continue to be in doubt.

Although uncertainties associated with knowledge of physical and biological processes could be substantially reduced by further research, some of these uncertainties are bound to remain large for many years, as explained in the report.

The report does not attempt to provide a single estimate of the likely consequences for humans and their societies of the physical and biological changes projected to be possible after a nuclear war. One reason is that the combinations of possible environmental perturbations are so large and the varieties of environmental and human systems are so numerous and complex that it would be an impossible task to look with detail into all of the ways in which those perturbations might result in an impact. Further, the environmental disruptions and dislocations from nuclear war would be of a magnitude for which there is no precedent. Our present interdependent, highly organized world has never experienced anything approaching the annihilation of people, structures, resources, and disruption of communications that would accompany a major exchange, even if severe climatic and environmental disturbances were not to follow it. The latter could aggravate the consequences profoundly. How the environmental perturbations which would occur at unprecedented scales and intensities would affect the functioning of human society is a highly uncertain subject requiring concerted research and evaluation. Nevertheless, whatever the uncertainties, there can be no doubt that there is a considerable probability a major nuclear war could gravely disrupt the global environment and world society. All possible effects do not have the same probability of occurrence. Sharpening these probabilities is a matter for a continuing research agenda.

The bases for these statements are to be found in the report, along with references to supporting or relevant information. From them we draw the following general conclusions:

1. Multiple nuclear detonations would result in considerable direct physical effects from blast, thermal radiation, and local fallout. The latter would be particularly important if substantial numbers of surface bursts were to occur since lethal levels of radiation from local fallout would extend hundreds of kilometers downwind of detonations.
2. There is substantial reason to believe that a major nuclear war could lead to large-scale climatic perturbations involving drastic reductions in light levels and temperatures over large regions within days and changes in precipitation patterns for periods of days, weeks, months, or longer. Episodes of short term, sharply depressed temperatures could also produce serious impacts—particularly if they occur during critical periods within the growing season. There is no reason to assert confidently that there would be no effects of this character and, despite uncertainties in our understanding,

it would be a grave error to ignore these potential environmental effects. Any consideration of a post-nuclear-war world would have to consider the consequences of the *totality* of physical effects. The biological effects then follow.

3. The systems that currently support the vast majority of humans on Earth (specifically, agricultural production and distribution systems) are exceedingly vulnerable to the types of perturbations associated with climatic effects and societal disruptions. Should those systems be disrupted on a regional or global scale, large numbers of human fatalities associated with insufficient food supplies would be inevitable. Damage to the food distribution and agricultural infrastructure alone, (i.e., without any climatic perturbations) would put a large portion of the Earth's population in jeopardy of a drastic reduction in food availability.
4. Other indirect effects from nuclear war could individually and in combination be serious. These include disruptions of communications, power distribution, and societal systems on an unprecedented scale. In addition, potential physical effects include reduction in stratospheric ozone and, after any smoke had cleared, associated enhancement of ultraviolet radiation; significant global-scale radioactive fallout; and localized areas of toxic levels of air and water pollution.
5. Therefore, the indirect effects on populations of a large-scale nuclear war, particularly the climatic effects caused by smoke, could be potentially more consequential globally than the direct effects, and *the risks of unprecedented consequences are great for noncombatant and combatant countries alike.*

A new perspective on the possible consequences of nuclear war that takes into account these findings is clearly indicated. In these circumstances, it would be prudent for the world scientific community to continue research on the entire range of possible effects, with close interaction between biologists and physical scientists. It would be appropriate for an international group of scientists to reappraise those findings periodically and to report its appraisal to governments and citizen groups. Increased attention is urgently required to develop a better understanding of potential societal responses to nuclear war in order to frame new global perspectives on the large-scale, environmental consequences. This task is a special challenge to social scientists.

In arriving at these conclusions, we have been moderate in several respects. We have tried to state and examine all challenges to theories about environmental effects of nuclear war, to minimize speculative positions and to factor valid criticisms into discussions and conclusions. Uncertainties in the projections could either reduce or enhance the estimated effects in specific cases.

Nevertheless, as representatives of the world scientific community drawn together in this study, we conclude that many of the serious global environmental effects are sufficiently probable to require widespread concern. Because of the possibility of a tragedy of an unprecedented dimension, any disposition to minimize or ignore the widespread environmental effects of a nuclear war would be a fundamental disservice to the future of global civilization.

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Vol. I

Executive Summary

This volume presents the results of an assessment of the climatic and atmospheric effects of a large nuclear war. The chapters in the volume follow a logical sequence of development, starting with discussions of nuclear weapons effects and possible characteristics of a nuclear war. The report continues with a treatment of the consequent fires, smoke emissions, and dust injections and their effects on the physical and chemical processes of the atmosphere. This is followed by a chapter dealing with long-term radiological doses. The concluding chapter contains recommendations for future research and study.

In assessments of this type, a variety of procedural options are available, including, for example, "worst case" analyses, risk analyses, and "most probable" analyses. All of these approaches have relevance for the subject addressed here due to the large uncertainties which surround many aspects of the problem. Some of these uncertainties are inherent in studies of nuclear war and some are simply the result of limited information about natural physical processes. In general, in making assumptions about scenarios, models, and magnitudes of injections, and in estimating their atmospheric effects, an attempt has been made to avoid "minimum" and "worst case" analyses in favor of a "middle ground" that encompasses, with reasonable probability, the atmospheric and climatic consequences of a major nuclear exchange.

The principal results of this assessment, arranged roughly in the same order as the more detailed discussions contained in the body of this volume, are summarized below. The Executive Summary of Volume II, which describes the ecological and agricultural consequences of a nuclear war, is included at the end of this volume.

1. DIRECT EFFECTS OF NUCLEAR EXPLOSIONS

The two comparatively small detonations of nuclear weapons in Japan in 1945 and the subsequent higher yield atmospheric nuclear tests preceding the atmospheric test ban treaty of 1963 have provided some information on the direct effects of nuclear explosions. Typical modern weapons carried by today's missiles and aircraft have yields of hundreds of kilotons or more. If detonated, such explosions would have the following effects:

- In each explosion, thermal (heat) radiation and blast waves would result in death and devastation over an area of up to 500 km^2 per megaton.

km^2, an area typical of a major city. The extent of these direct effects depends on the yield of the explosion, height of burst, and state of the local environment. The destruction of Hiroshima and Nagasaki by atomic bombs near the end of World War II provides examples of the effects of relatively *small* nuclear explosions.

- Nuclear weapons are extremely efficient incendiary devices. The thermal radiation emitted by the nuclear fireball, in combination with the accidental ignitions caused by the blast, would ignite fires in urban/industrial areas and wildlands of a size unprecedented in history. These fires would generate massive plumes of smoke and toxic chemicals. The newly recognized atmospheric effects of the smoke from a large number of such fires are the major focus of this report.
- For nuclear explosions that contact land surfaces (surface bursts), large amounts (of the order of 100.000 tonne per megaton of yield) of dust, soil, and debris are drawn up with the fireball. The larger dust particles, carrying about half of the bomb's radioactivity, fall back to the surface mostly within the first day, thereby contaminating hundreds of square kilometers near and downwind of the explosion site. This local fallout can exceed the lethal dose level.
- All of the radioactivity from nuclear explosions well above the surface (airbursts) and about half of the radioactivity from surface bursts would be lofted on particles into the upper troposphere or stratosphere by the rising fireballs and contribute to longer term radioactive fallout on a global scale.
- Nuclear explosions high in the atmosphere, or in space, would generate an intense electromagnetic pulse capable of inducing strong electric currents that could damage electronic equipment and communications networks over continent-size regions.

2. STRATEGIES AND SCENARIOS FOR A NUCLEAR WAR

In the forty years since the first nuclear explosion, the five nuclear powers, but primarily the U.S. and the U.S.S.R., have accumulated very large arsenals of nuclear weapons. It is impossible to forecast in detail the evolution of potential military conflicts. Nevertheless, enough of the general principles of strategic planning have been discussed that plausible scenarios for the development and immediate consequences of a large-scale nuclear war can be derived for analysis.

- NATO and Warsaw Pact nuclear arsenals include about 24,000 strategic and theatre nuclear warheads totaling about 12,000 megatons. The arsenals now contain the equivalent explosive power of about one million "Hiroshima-size" bombs.
- A plausible scenario for a global nuclear war could involve on the order of 6000 Mt divided between more than 12,000 warheads. Because of its obvious importance, the potential environmental consequences of an exchange of roughly this size are examined. The smoke-induced atmospheric consequences discussed in this volume are, however, more dependent on the number of nuclear explosions occurring over cities and industrial centers than on any of the other assumptions of the particular exchange.
- Many targets of nuclear warheads, such as missile silos and some military bases, are isolated geographically from population centers. Nevertheless, enough important military and strategic targets are located near or within cities so that collateral damage in urban and industrial centers from a counterforce nuclear strike could be extensive. As a result, even relatively limited nuclear attacks directed at military-related targets could cause large fires and smoke production.
- Current strategic deterrence policies imply that, in an escalating nuclear conflict many warheads might be used directly against urban and industrial centers. Such targeting would have far-reaching implications because of the potential for fires, smoke production, and climatic change.

3. THE EXTENT OF FIRES AND GENERATION OF SMOKE

During World War II, intense city fires covering areas as large as 10 to 30 square kilometers were ignited by massive incendiary bombing raids, as well as by the relatively small nuclear explosions over Hiroshima and Nagasaki. Because these fires were distributed over many months, the total atmospheric accumulation of smoke generated by these fires was small. Today, in a major nuclear conflict, thousands of very intense fires, each covering up to a few hundred square kilometers, could be ignited simultaneously in urban areas, fossil fuel processing plants and storage depots, wildlands, and other locations. Because there have never been fires as large and as intense as may be expected, no appropriate smoke emission measurements have been made. Estimates of emissions from such fires rely upon extrapolation from data on much smaller fires. This procedure may introduce considerable error in quantifying smoke emissions, especially in making estimates for intense fire situations.

- About 70% of the populations of Europe, North America and the Soviet Union live in urban and suburban areas covering a few hundred thousand square kilometers and containing more than ten thousand million tonne of combustible wood and paper. If about 25–30% of this were to be ignited, in just a few hours or days, tens of millions to more than a hundred million tonne of smoke could be generated. About a quarter to a third of the emitted smoke from the flaming combustion of this material would be amorphous elemental carbon, which is black and efficiently absorbs sunlight.
- Fossil fuels (e.g., oil, gasoline, and kerosene) and fossil fuel-derived products (including plastics, rubber, asphalt, roofing materials, and organochemicals) are heavily concentrated in cities and industrial areas; flaming combustion of a small fraction (~25 30%) of the few thousand million tonne of such materials currently available could generate 50–150 million tonne of very sooty smoke containing a large fraction (50% or greater) of amorphous elemental carbon. The burning of 25–30% of the combustible materials of the developed world could occur with near total burnout of less than one hundred of the largest industrialized urban areas.
- Fires ignited in forests and other wildlands could consume tens to hundreds of thousands of square kilometers of vegetation over days to weeks, depending on the state of the vegetation, and the extent of firespread. These fires could produce tens of millions of tonne of smoke in the summer half of the year, but considerably less in the winter half of the year. Because wildland fire smoke contains only about 10% amorphous elemental carbon, it would be of secondary importance compared to the smoke created by urban and industrial fires, although its effects would not be negligible.
- The several tens of millions of tonne of sub-micron dust particles that could be lofted to stratospheric altitudes by surface bursts could reside in the atmosphere for a year or more. The potential climatic effects of the dust emissions, although substantially less than those of the smoke, also must be considered.

4. THE EVOLUTION AND RADIATIVE EFFECTS OF THE SMOKE

The sooty smoke particles rising in the hot plumes of large fires would consist of a mixture of amorphous elemental carbon, condensed hydrocarbons, debris particles, and other substances. The amount of elemental carbon in particles with effective spherical diameters on the order of 0.1 μm to perhaps 1.0 μm would be of most importance in calculating the potential effect on solar radiation. Such particles can be spread globally by the winds and remain suspended for days to months.

- Large hot fires create converging surface winds and rapidly rising fire plumes which, within minutes, can carry smoke particles, ash and other fire products, windblown debris, and water from combustion and the surrounding air to as high as 10–15 kilometers. The mass of particles deposited aloft would depend on the rate of smoke generation, the intensity of the fire, local weather conditions, and the effectiveness of scavenging processes in the convective column.
- As smoke-laden, heated air from over the fire rises, adiabatic expansion and entrainment would cause cooling and condensation of water vapor that could lead, in some cases, to the formation of a cumulonimbus cloud system. Condensation-induced latent heating of the rising air parcels would help to loft the smoke particles to higher altitudes than expected from the heat of combustion alone.
- Although much of the water vapor drawn up from the boundary layer would condense, precipitation might form for only a fraction of the fire plumes. In the rising fire columns of such fires, soot particles would tend to be collected inefficiently by the water in the cloud. Smoke particles however, are generally composed of a mixture of substances and might, at least partially, be incorporated in water droplets or ice particles by processes not now well understood. Smoke particles that are captured could again be released to the atmosphere as the ice or water particles evaporate in the cloud anvils or in the environment surrounding the convective clouds. Altogether, an unknown fraction of the smoke entering the cloud would be captured in droplets and promptly removed from the atmosphere by precipitation.
- Not all fires would, however, induce strong convective activity. This depends on fuel loading characteristics and meteorological conditions. It is assumed in current studies that 30–50% of the smoke injected into the atmosphere from all fires would be removed by precipitation within the first day, and not be available to affect longer-term large-scale, meteorological processes. This assumption is a major uncertainty in all current assessments. For the fire and smoke assumptions made in this study, the net input of smoke to the atmosphere after early scavenging is estimated to range from 50 to 150 million tonne, containing about 30 million tonne of amorphous elemental carbon.
- Smoke particles generated by urban and fossil fuel fires would be strong absorbers of solar radiation, but would be likely to have comparatively limited effects on terrestrial longwave radiation, except perhaps under some

special circumstances. If 30 million tonne of amorphous elemental carbon were produced by urban/industrial fires and spread over Northern Hemisphere mid-latitudes, the insolation at the ground would be reduced by at least 90%. The larger quantities of smoke that are possible in a major nuclear exchange could reduce light levels under dense patches to less than 1% of normal, and, on a daily average, to just several percent of normal, even after the smoke has spread widely.

- Because of the large numbers of particles in the rising smoke plumes and the very dense patches of smoke lasting several days thereafter, coagulation (adhering collisions) would lead to formation of fewer, but somewhat larger, particles. Coagulation of the particles could also occur as a result of coalescence and subsequent evaporation of rain droplets or ice particles. Because optical properties of aerosols are dependent on particle size and morphology, the aggreated aerosols may have different optical properties than the initial smoke particles, but the details, and even the sign, of such changes are poorly understood. The optical properties of fluffy soot aggregates that may be formed in dense oil plumes, however, seem to be relatively insensitive to their size. This is not the case for more consolidated particle agglomerates.
- Little consideration has yet been given to the possible role of meteorological processes on domains between fire plume and continental scales. Mesoscale and synoptic-scale motions might significantly alter, mix, or remove the smoke particles during the first several days. Studies to examine quantitatively the microphysical evolution of smoke particles during this period are needed. While changes in detailed understanding are expected, a significant fraction of the injected smoke particles is likely to remain in the atmosphere and affect the large-scale weather and climate.

5. SMOKE-INDUCED ATMOSPHERIC PERTURBATIONS

In a major nuclear war, continental scale smoke clouds could be generated within a few days over North America, Europe, and much of Asia. Careful analysis and a hierarchy of numerical models (ranging from one-dimensional global-average to three-dimensional global-scale models) have been used to estimate the transport, transformation, and removal of the smoke particles and the effects of the smoke on temperature, precipitation, winds, and other important atmospheric properties. All of the simulations indicate a strong potential for large-scale weather disruptions as a result of the smoke injected by extensive post-nuclear fires. These models, however, still have important simplifications and uncertainties that may affect the fidelity and the details of their predictions. Nonetheless, these uncertainties probably do not affect the general character of the calculated atmospheric response.

- For large smoke injections reaching altitudes of several kilometers or more and occurring from spring through early fall in the Northern Hemisphere, average land surface temperatures beneath dense smoke patches could decrease by 20–40°C below normal in continental areas within a few days, depending on the duration of the dense smoke pall and the particular meteorology. Some of these patches could be carried long distances and create episodic cooling. During this initial period of smoke dispersion, anomalies could be spatially and temporally quite variable while patchy smoke clouds strongly modulate the insolation reaching the surface.
- Smoke particles would be spread throughout much of the Northern Hemisphere within a few weeks, although the smoke layer would still be far from homogeneous. For spring to early fall injections, solar heating of the particles could rapidly warm the smoke layer and lead to a net upward motion of a substantial fraction of the smoke into the upper troposphere and stratosphere. The warming of these elevated layers could stabilize the atmosphere and suppress vertical movement of the air below these layers, thereby extending the lifetime of the particles from days to perhaps several months or more.
- Average summertime land surface temperatures in the Northern Hemisphere mid-latitudes could drop to levels typical of fall or early winter for periods of weeks or more with convective precipitation being essentially eliminated, except possibly at the southern edge of the smoke pall. Cold, near-surface air layers might lead initially to fog and drizzle, especially in coastal regions, lowland areas, and river valleys. In continental interiors, periods of very cold, mid-winter-like temperatures are possible. In winter, light levels would be strongly reduced, but the initial temperature and precipitation perturbations would be much less pronounced and might be essentially indistinguishable in many areas from severe winters currently experienced from time to time. However, such conditions would occur simultaneously over a large fraction of the mid-latitude region of the Northern Hemisphere and freezing cold air outbreaks could penetrate southward into regions that rarely or never experience frost conditions.
- In Northern Hemisphere subtropical latitudes, temperatures in any season could drop well below typical cool season conditions for large smoke injections. Temperatures could be near or below freezing in regions where temperatures are not typically strongly moderated by warming influence from the oceans. The convectively driven monsoon circulation, which is of critical importance to subtropical ecosystems, agriculture, and is the main

source of water in these regions, could be essentially eliminated. Smaller scale, coastal precipitation might, however, be initiated.

- Strong solar heating of smoke injected into the Northern Hemisphere between April and September would carry the smoke upwards and equatorward, strongly augmenting the normal high altitude flow to the Southern Hemisphere (where induced downward motions might tend to slightly suppress precipitation). Within one or two weeks, thin, extended smoke layers could appear in the low to mid-latitude regions of the Southern Hemisphere as a precursor to the development of a more uniform veil of smoke with a significant optical depth (although substantially smaller than in the Northern Hemisphere). The smoke could induce modest cooling of land areas not well buffered by air masses warmed over nearby ocean areas. Since mid-latitudes in the Southern Hemisphere would already be experiencing their cool season, temperature reductions would not likely be more than several degrees. In more severe, but less probable, smoke injection scenarios, climatic effects in the Southern Hemisphere could be enhanced significantly, particularly during the following austral spring and summer.
- Much less analysis has been made of the atmospheric perturbations following the several week, acute climatic phase subsequent to a nuclear war involving large smoke injections. Significant uncertainties remain concerning processes governing the longer-term removal of smoke particles by precipitation scavenging, chemical oxidation, and other physical and chemical factors. The ultimate fate of smoke particles in the perturbed atmospheric circulation is also uncertain, both for particles in the sunlit and stabilized upper troposphere and stratosphere and in the winter polar regions, where cooling could result in subsidence that could move particles downward from the stratosphere to altitudes where they could later be scavenged by precipitation.
- Present estimates suggest that smoke lofted to levels (either directly by fire plumes or under the influence of solar heating) which are, or become, stabilized, could remain in the atmosphere for a year or more and induce long-term (months to years) global-scale cooling of several degrees, especially after the oceans have cooled significantly. For such conditions, precipitation could also be reduced significantly. Reduction of the intensity of the summer monsoon over Asia and Africa could be a particular concern. Decreased ocean temperatures, climatic feedback mechanisms (e.g., ice-albedo feedback), and concurrent ecological changes could also prolong the period of meteorological disturbances.

6. ATMOSPHERIC CHEMISTRY IN A POST-NUCLEAR-WAR ENVIRONMENT

Nuclear explosions and the resultant fires could generate large quantities of chemical compounds that might themselves be toxic. In addition, the chemicals could alter the atmospheric composition and radiative fluxes in ways that could affect human health, the biosphere, and the climate.

- Nitrogen oxides (NO_x) created by nuclear explosions of greater than several hundred kilotons would be lofted into the stratosphere. Depending on the total number of high yield weapons exploded, the NO_x would catalyze chemical reactions that, within a few months time, could reduce Northern Hemisphere stratospheric ozone concentrations by 10 to 30% in an atmosphere free of aerosols. Recovery would take several years. However, if the atmosphere were highly perturbed due to smoke heating and by injection of gaseous products from fires, the long-term ozone changes could be enhanced substantially in ways that cannot yet be predicted.
- Ozone reductions of tens of percent could increase surface intensities of biologically-active ultraviolet (UV) radiation by percentages of up to a few times as much. The presence of smoke would initially prevent UV-radiation from reaching the surface by absorbing it. The smoke, however, might also prolong and further augment the long-term ozone reduction as a result of smoke-induced lofting of soot and reactive chemicals, consequent heating of the stratosphere, and the occurrence of additional chemical reactions.
- Large amounts of carbon monoxide, hydrocarbons, nitrogen and sulfur oxides, hydrochloric acid, pyrotoxins, heavy metals, asbestos, and other materials would be injected into the lower atmosphere near the surface by flaming and smoldering combustion of several thousand million tonne of cellulosic and fossil fuel products and wind-blown debris. Before deposition or removal, these substances, some of which are toxic, could be directly and/or indirectly harmful to many forms of life. In addition, numerous toxic chemical compounds could be released directly into the environment by blast and spillage, contaminating both soil and water. This complex and potentially very serious subject has so far received only cursory consideration.
- If the hydrocarbons and nitrogen oxides were injected into an otherwise unperturbed troposphere, they could enhance average background ozone concentrations several-fold. Such ozone increases would not significantly offset the stratospheric ozone decrease, which also would be longer lasting. It is highly questionable, however, whether such large ozone increases could indeed occur in the presence of smoke because ozone generation in

the troposphere requires sunlight as well as oxides of nitrogen. It is possible that, in the smoke perturbed atmosphere, the fire-generated oxides of nitrogen could be removed before photochemical ozone production could take place.

- Precipitation scavenging of nitrogen, sulfur, and chlorine compounds dispersed by the fire plumes throughout the troposphere could increase rainfall acidity by about an order of magnitude over large regions for up to several months. This increased acidity could be neutralized to some degree by alkaline dust or other basic (as opposed to acidic) compounds.
- Rapid smoke-induced cooling of the surface under dense smoke clouds could induce the formation of shallow, stable cold layers that might trap chemical emissions from prolonged smoldering fires near the ground. In such layers, concentrations of CO, $HC\ell$, pyrotoxins, and acid fogs could reach dangerous levels. The potential for local and regional effects in areas such as populated lowland areas and river valleys merits close attention.

7. RADIOLOGICAL DOSE

Near the site of an explosion, the health effects of prompt ionizing radiation from strategic nuclear warheads would be overshadowed by the effects of the blast and thermal radiation. However, because nuclear explosions create highly radioactive fission products and the emitted neutrons may also induce radioactivity in initially inert material near the detonation, radiological doses would be delivered to survivors both just downwind (local fallout) and out to hemispheric and global scales (global fallout).

- Local fallout of relatively large radioactive particles lofted by the number of surface explosions in the scenario postulated in this study could lead to lethal external gamma-ray doses (assuming no protective action is taken) during the first few days over about 7 percent of the land areas of the NATO and Warsaw Pact countries. Areas downwind of missile silos and other hardened targets would suffer especially high exposures. Survivors outside of lethal fallout zones could still receive debilitating radiation doses (exposure at half the lethal level can induce severe radiation sickness). In combination with other injuries or stresses, such doses could increase mortality. If large populations could be mobilized to move from highly radioactive zones or take substantial protective measures, the human impact of fallout could be greatly reduced.
- The uncertainty in these calculations of local fallout is large. Doses and areas for single nuclear explosions could vary by factors of 2-4 depending on meteorological conditions and assumptions in the models. A detailed

treatment of overlapping fallout plumes from multiple explosions could increase the areas considerably (by a factor of 3 in one sample case). Results are also sensitive to variations in the detonation scenario.

- Global fallout following the gradual deposition of the relatively small radioactive particles created by strategic air and surface bursts could lead to average Northern Hemisphere lifetime external gamma ray doses on the order of 10 to 20 rads. The peak values would lie in the northern midlatitudes where the average doses for the major nuclear war considered would be about 20 to 60 rads. Such doses, in the absence of other stresses, would be expected to have relatively minor carcinogenic and mutagenic effects (i.e., increase incidence at most a few percent above current levels). Smoke-induced perturbations that tend to stabilize the atmosphere and slow deposition of radioactive particles might reduce these estimated average doses by perhaps 15%.
- Intermediate time scale and long term global fallout would be deposited unevenly, largely because of meteorological effects, leading to "hotspots" of several hundred thousand square kilometers in which average doses could be as high as 100 rads and, consequently, large areas where doses would be substantially less than the average value.
- In the Southern Hemisphere and tropical latitudes, global fallout would produce much smaller, relatively insignificant, radiological doses about one-twentieth those in the Northern Hemisphere, even if cross-equatorial transport were accelerated by the smoke clouds. Additional local fallout would be important only within a few hundred kilometers downwind of any surface burst in the Southern Hemisphere.
- Additional considerations not factored into the above estimates are possible from several sources. Doses from ingestion or inhalation of radioactive particles could be important, especially over the longer term. Beta radiation could have a significant effect on the biota coming into contact with the local fallout. Fission fractions of smaller modern weapons could be twice the assumed value of 0.5; adding these to the scenario mix could cause a 20% increase in areas of lethal fallout. General tactical and theater nuclear weapons, ignored in these calculations, could also cause a 20% increase in lethal local fallout areas in certain geographical regions, particularly in Europe. The injection into the atmosphere of radionuclides created and stored by the civilian nuclear power industry and military reactors, a possibility considered remote by some, could increase estimates of long-term local and global radiological doses to several times those estimated for weapons alone.

8. TASKS FOR THE FUTURE

Extensive research and careful assessment over the past few years have indicated that nuclear war has the potential to modify the physical environment in ways that would dramatically impair biological processes. The perturbations could impact agriculture, the proper functioning of natural ecosystems, the purity of essential air and water resources, and other important elements of the global biosphere. Because current scientific conclusions concerning the response of the atmosphere to the effects of nuclear war include uncertainties, research can and should be undertaken to reduce those uncertainties that are accessible to investigation.

- Laboratory and field experiments are needed to improve estimates of the amount and physical characteristics of the smoke particles that would be produced by large fires, particularly by the combustion of fossil fuels and fossil fuel-derived products present in urban and industrial regions. Experimental conditions should be designed to emulate as much as possible the effects of large-scale fires.
- Laboratory, field, and theoretical studies are needed to determine the potential scavenging rates of smoke particles in the convective plumes of large fires and the scavenging processes that operate on intermediate and global scales as the particles disperse.
- Further theoretical calculations of the seasonal response of the atmosphere to smoke emissions from large fires are needed, particularly of the extent of the perturbation to be expected at early times, when the smoke is freshly injected and patchy. Simulations must be made for later times from months to a year or more, when the atmosphere has been highly perturbed and a substantial fraction of the smoke may have been lofted to high altitudes. Closer attention should be paid to the possible effects in low latitudes and in the Southern Hemisphere, where the climatic effects are likely to be much more important than the direct effects of the nuclear detonations, which are expected to be confined largely to the Northern Hemisphere.
- Laboratory and theoretical studies are needed of the potential chemical alterations of the atmosphere on global and local scales, and of the extent that smoke particles could affect and might be removed by chemical reactions high in the atmosphere.
- Radiological calculations should be undertaken using models that more realistically treat the overlap of fallout plumes, complex meteorological conditions, and that consider both external and internal doses. The question of the possible release of radioactivity from nuclear fuel cycle facilities in a nuclear war should be explored more thoroughly. Patterns of land use

and likely targeting strategy should be used in estimating the potential significance of various scenarios.

AUTHORS' NOTE

The term "nuclear winter" has been applied in some previous analyses of the environmental consequences of a nuclear exchange to describe the multitude of possible effects. In its original usage, this term envisaged the combination of darkened skies, subfreezing temperatures, and extensive toxic and radioactive pollution that, to a more or less severe degree, might follow a nuclear war. The phrase has since, however, come to be associated primarily with the most severe possibilities. Although it is a convenient metaphor for use in describing the generic consequences, we have chosen to avoid use of the term "nuclear winter" in this study because it does not, in a strict scientific sense, properly portray the range, complexity, and dependencies of the potential global scale environmental consequences of a nuclear war. By this choice, we are not suggesting that the environmental effects of a major nuclear exchange would be inconsequential; to the contrary, we find that they would be substantial and significant.

APPENDIX 1

Executive Summary of Volume II: Ecological and Agricultural Effects

by Mark A. Harwell and Thomas C. Hutchinson

The potential consequences to the global environment of a nuclear war have been the focus of several studies in the four decades since the first detonations of nuclear weapons in Japan. During this time, the *potential consequences* that would ensue from a modern nuclear war have increased dramatically, and the combination of much larger yields and much greater numbers of nuclear warheads could now result in a large-scale nuclear war having little in common with the relatively limited experiences of Hiroshima and Nagasaki. Simultaneously, the projections of the magnitude of impacts from a nuclear war have also increased steadily; however, the *perception of the consequences* of a large-scale nuclear war consistently have lagged behind the reality. New global-scale phenomena continue to be identified, even up to the present, and there remains a concern that decision-makers are operating with obsolete analyses and basing their policies on a foundation of misunderstanding of the total consequences of nuclear war.

The SCOPE-ENUWAR project had as one of its objectives the development of a comprehensive understanding of the nature of a post-nuclear war world, based on the full range of available information and models. Volume I of the ENUWAR report presented the bases for estimating potential effects on the physical environment, including possible climatic disturbances as well as fallout, UV-B, air pollutants, and other effects. The present volume takes up where the first left off, by specifically considering the potential consequences of such physical and chemical stresses on biological systems and on the ultimate endpoint of concern, i.e., effects on the global human population.

The approach taken in the biological analyses was to synthesize current understanding of the responses of ecological and agricultural systems to perturbations, relying on the expertise of over 200 scientists from over 30 countries around the Earth. Much of the synthesis took place in the context of a series of workshops that addressed specific issues; other work included conducting simulation modeling and performing detailed calculations of potential effects on the human populations of representative countries. We do not present the evaluation of a single nuclear war scenario as estimated by a single methodology; rather, a suite of methodologies were drawn upon collectively to develop an image of the aftermath of a large-scale nuclear war. The range of possible nuclear war scenarios is great; the estimates from the physical scientists of potential climatic consequences are not yet certain and continue to evolve with time. Those estimates are complex in their spatial and temporal distribution over the Earth, and the global landscape is covered by extremely complex ecological, agricultural, and human systems that react to perturbations in complex manners. For these reasons, the present volume investigates the *vulnerability* of these sytems to the types of perturbations possible after a nuclear war, offering readers the opportunity to form their own specific projections of biological and human consequences of providing calculations of vulnerabilities to benchmark assumptions.

Nevertheless, many conclusions are evident from considering these vulnerabilities to nuclear war perturbations. These include:

- Natural ecosystems are vulnerable to extreme climatic disturbances, with differential vulnerability depending on the ecosystem type, location, and season of effects. Temperature effects would be dominant for terrestrial ecosystems in the Northern Hemisphere and in the tropics and sub- tropics; light reductions would be most important for oceanic ecosystems; precipitation effects would be more important to grasslands and many Southern Hemisphere ecosystems.
- The potential for synergistic responses and propagation of effects through ecosystems implies much greater impacts than can be understood by addressing perturbations in isolation. For example, increased exposure to UV-B and to mixtures of air pollutants and radiation, while not crucially harmful for any one stress, might collectively be very detrimental or lethal to sensitive systems because of synergistic interactions.
- Fires as a direct consequence of a major nuclear exchange could consume large areas of natural ecosystems, but fire-vulnerable ecosystems are generally adapted to survive or regenerate via a post-fire succession. Other direct effects of nuclear detonations on ecological systems would be limited in extent or effect.
- The recovery of natural ecosystems from the climatic stresses postulated for an acute phase following a major nuclear war would depend on normal adaptations to disturbance, such as through presence of spores, seed banks, seedling banks, vegetative growth, and coppicing. For some systems, the initial damage could be very great and recovery very slow, with full recovery to the pre-disturbed state being unlikely. Human-ecosystem interactions could act to retard ecological recovery.
- Because of limitations in the amounts of utilizable energy, natural ecosystems cannot replace agricultural systems in supporting the majority of humans on Earth, even if those natural ecosystems were not to suffer any impacts from nuclear war.

- Consequently, human populations are highly vulnerable to disruptions in agricultural systems.
- Agricultural systems are very sensitive to climatic and societal disturbances occurring on regional to global scales, with reductions in or even total loss of crop yields possible in response to many of the potential stresses. These conclusions consistently follow from a suite of approaches to evaluating vulnerabilities, including historical precedents, statistical analyses, physiological and mechanistic relationships, simulation modeling, and reliance on expert judgment.
- The vulnerabilities of agricultural productivity to climatic perturbations are a function of a number of different factors, any one of which could be limiting. These factors include: insufficient integrated thermal time for crops over the growing season; shortening of the growing season by reduction in a frost-free period in response to average temperature reductions; increasing of the time required for crop maturation in response to reduced temperatures; the combination of the latter two factors to result in insufficient time for crops to mature prior to onset of killing cold temperatures; insufficient integrated time of sunlight over the growing season for crop maturation; insufficient precipitation for crop yields to remain at high levels; and the occurrence of brief episodic events of chilling or freezing temperatures at critical times during the growing season.
- Potential disruptions in agricultural productivity and/or in exchange of food across national boundaries in the aftermath of a large-scale nuclear war are factors to which the human population is highly vulnerable. Vulnerability is manifested in the quantities and duration of food stores existing at any point in time, such that loss of the continued agricultural productivity or imports that maintain food levels would lead to depletion of food stores for much of the world's human population in a time period before it is likely that agricultural productivity could be resumed.
- Under such a situation, the majority of the world's population is at risk of starvation in the aftermath of a nuclear war. Risk is therefore exported from combatant countries to noncombatant countries, especially those dependent on others for food and energy subsidies and those whose food stores are small relative to the population.
- The high sensitivity of agricultural systems to even relatively small alterations in climatic conditions indicates that many of the unresolved issues among the physical scientists are less important, since even their lower estimates of many effects could be devastating to agricultural production and thereby to human populations on regional or wider scales.
- Longer-term climatic disturbances, if they were to occur, would be at least as important to human survival as the acute, early extremes of temperature and light reductions, suggesting that much greater attention should be given to those issues. Similarly, much greater attention is needed to

resolve uncertainties in precipitation reduction estimates, since many of the agricultural systems are water-limited, and reduced precipitation can significantly reduce total production.

- Factors related to the possibility and rates of redevelopment of an agricultural base for the human population would have much influence on the long-term consequences to the human population. Interactions with societal factors would be very important.
- Global fallout is not likely to result in major ecological, agricultural, or human effects, as compared to effects of other global disturbances. Local fallout, on the other hand, could be highly consequential to natural and agricultural systems and to humans; however, the extent of coverage of lethal levels of local fallout and the levels of internal doses to humans from such fallout are inadequately characterized.
- Human populations are highly vulnerable to possible societal disruptions within combatant and noncombatant countries after a large-scale nuclear war, such as in the consequent problems of distribution of food and other limited resources among the immediate survivors. This is an area requiring a level of serious scientific investigation that has not yet been brought to bear on these issues.

As a part of the SCOPE-ENUWAR project, a workshop was held in Hiroshima, Japan in order for the scientists to gain a fuller appreciation of the human consequences of nuclear detonations. The considerations listed above indicate that as devastating as the Japanese atomic bombings were, as consequential to their victims even to the present day, and as important to the development of the 20th Century, they cannot provide a sense of what the global aftermath of a modern nuclear war could be like. Hiroshima today is a thriving, dynamic city reborn from complete devastation by interactions and support from the outside world; after a large-scale nuclear war, there would be essentially no outside world, and qualitatively new global-scale effects would occur that could devastate not just an urban population but the entirety of humanity. Although issues remain to be resolved, the information in this volume demonstrates some of the great vulnerabilities of agricultural, ecological, and societal support systems to the potential direct and indirect consequences of nuclear war. This demonstration of global frailties mandates the formulation of new global perspectives on avoiding the aftermath of nuclear war.

RECOMMENDATIONS FOR FURTHER RESEARCH

One of the more important outcomes of the process of holding workshops around the world to investigate the environmental consequences of nuclear war has been the recognition of the broad subject areas that have not yet received adequate research treatment. It is instructive to realize that many of the following listed topic areas involve the field of stress ecology; thus, improved understanding of the environmental consequences of nuclear war will progress in concert with advances in stress ecology.

During the synthesis workshop held at the Wivenhoe Conference Center, University of Essex in June 1985, the review committee for this volume compiled their recommendations for further research. (See Appendix A of Volume II for a listing of review committee members.) These were supplemented by a more detailed list compiled by M. Harwell, T. Hutchinson, W. Cropper, Jr., and C. Harwell. (See Appendix B of Volume II for both sets of recommendations.)

In brief summary:

1. Progress in this field will be strongly dependent on research efforts in stress ecology.
2. There needs to be an enhanced cooperation between physical and biological scientists in identifying the research priorities of the physical scientists. Examples of biologically-based suggestions include:
    - Climatologists need to do research on short-term variability in climate and the relationships between average climatic conditions and variances in climatic conditions in a post-nuclear-war framework.
    - Better resolution is needed of the potential levels of air pollution likely to result from a nuclear war.
    - Better resolution is needed of the potential levels of precipitation reductions likely to result from a nuclear war.
    - The potential for long-term climatic changes needs investigation, particularly involving feedback mechanisms, such as albedo changes, ice pack dynamics, and greenhouse-effect gases.
3. There is a need for models of environmental and ecosystem responses extending into the chronic post-nuclear-war phase. These should include better estimates of chronic phase parameters of temperature, light, and precipitation. These should also include much more experimental work on the effects of beta-radiation on plants and crops. Microcosm or enclosure experiments would be appropriate.
4. Explicit experimentation is needed to investigate synergisms including, for example, the interactive effects on biota of radiation, UV-B, and air pollution.
5. Synthesis studies addressing the specific conditions at local, regional, and national levels are the next logical step inthe process of understanding the effects of global nuclear war.
6. There is a need for further analysis of food stores, the likelihood of their destruction in a major nuclear war, their location, and other data, on a country-by-country basis.

7. Experiments need to be conducted using microcosms and enclosed whole ecosystems and agricultural systems to examine systems-level responses to climatic disturbances; particular attention can be given to recovery processes by using this approach.
8. New model development is needed to determine responses of ecosystems to climatic perturbations. Such models will have general applicability to other important issues in addition to nuclear war.
9. Existing sophisticated models of local fallout patterns need to be used to evaluate the range of dose levels that would be experienced after a nuclear war, based on a variety of nuclear war scenarios and weather conditions. Similarly, existing dose models need to be used to evaluate the range of internal radiation doses to be expected in the aftermath of a large-scale nuclear war.
10. There is a critical need for comprehensive and concerted study of the potential societal responses to nuclear war.

Comments on

"The Potential Effects of Nuclear War on the Climate," a report to the United States Congress, by Caspar W. Weinberger, Secretary of Defense

by

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March 12, 1985

This report is very incomplete and contains a number of misrepresentations. As a scientist who has been involved with climate research for the past 11 years, with cooperative research with the Soviets for the past 6 years, and with nuclear winter research for the past 2 years, I feel I am qualified to comment on this report. I will concentrate my remarks on Section 4, Soviet Activities on Climatic Effects, because I feel that this section needs the most correction.

Sec. 1107 (b) (1) of the Department of Defense Authorization Act requests a "detailed review and assessment of the current scientific studies...", but Section 1 of this report only discusses one study, the TTAPS report, which was completed a year and a half ago, and ignores the many studies that have been published since then. It does not even discuss the TTAPS report in detail.

In Section 2, the statement at the beginning of the fourth paragraph, that, "These observations are consistent with the findings in the NAS report," is not true, as can be easilly seen in the quote beginning at the bottom of page 6. The NAS report concluded that nuclear winter is a "clear possibility." This is not consistent with the Defense Science Board which claims that no long-term climatic effects are just as likely as months of sub-freezing temperatures.

Section 3 does not seem to me to be a "thorough evaluation of the implications" as called for in the Act. I would like to point out that even though they claim that urban populations are not targeted, there are many military targets in urban areas, so the effect is the same. Claiming that Star Wars will prevent nuclear winter is ludicrous, since we do not even know if such a system would work, and if it would, it would not be in place for decades. Nuclear winter could happen today. How is present policy affected?

In Section 4, several issues are misrepresented. The main point here is that the Soviets agree with our research results. They have been involved from the beginning in the research, and their results confirm the results obtained by Americans. In fact the first three-dimensional general circulation model experiment to be published was the one done by Aleksandrov and Stenchikov, before the Americans published theirs, and even before TTAPS was published. It would be impossible for their results to be independent, and this is not the point. Three-dimensional climate modeling was invented in the United States, so that anyone attempting it later would have to start with what had been done previously. In addition, the laws of physics know no national boundaries. The same equations apply in the Soviet Union equally well as they do here.

It is claimed that the work of Aleksandrov is "crude" and "flawed." Every single study done so far on nuclear winter could be similarly criticized, since no model yet has considered the climate system in all its complexity. No one has computers large and fast enough to do this, and we do not understand the physics of all the processes well enough. The approach that has been taken so far is to simplify the model enough so that the calculation can be done in a reasonable time on the available computer, yet retain the important physics in the model. This has been the approach of every study, including my own. It is also claimed that his work was done with an "obsolete" model. Because the Soviets had smaller computers available to them, they used a climate model that was simpler than the current ones in use in the United States, but it is by no means obsolete; it only looks at the world in slightly less detail. The fact that their results agree with the American results is proof of this. In even the most simple model of the atmosphere, if you put enough smoke into the atmosphere, very little light will reach the ground, and it will get very cold.

In the report it is claimed that Soviet interest in this topic provides them additional access to U.S. scientists and technology. This is absolutely false. The

Soviets have been cooperating with us in the field of environmental protection (Working Group VIII) for the past 10 years. Under this agreement, Soviets have had access to our scientists and technology long before nuclear winter becames a research subject. In fact, I first met Dr. Aleksandrov in the summer of 1978, while he was spending 6 months at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, doing climate modeling using the Cray 1 computer, which at the time was the world's fastest. A few years later he spent another 6 months at Oregon State University, again using the Cray computer at NCAR. He has also spent time at Lawrence Livermore Laboratory doing climate research with the scientists there. This is one of our most secret nuclear weapons laboratories, and has one of the world's most extensive computer facilities. The nuclear winter research is a natural outgrowth of our previous cooperative effort, and does not afford the Soviets any more access than they already had.

In closing, I would like to say that having worked with the Soviet scientists both in the United States and the Soviet Union, I feel that the charge in this report that they are propagandists is both unfounded and inappropriate. I have not seen any examples of them misquoting research results for propaganda purposes.

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NATIONAL INSTITUTE FOR PUBLIC POLICY

THE NUCLEAR WINTER THESIS
AND U.S. STRATEGIC POLICY

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THE NUCLEAR WINTER THESIS AND U.S. STRATEGIC POLICY

Introduction

This analysis addresses the question of the implications of the nuclear winter thesis for U.S. strategic policy. In terms of its public impact, the thesis that 500-2,000 nuclear explosions might trigger climatic catastrophe would seem to be a non-event. The reason is that most people have long assumed that the prospects for personal and societal survival in a nuclear war were exceedingly modest. For defense professionals the nuclear winter thesis has some novel elements -- amounting to the suggestion that survival and recovery even from severely constrained nuclear attacks could be far more problematical than previously was assumed -- but to those who have always held to an undifferentiated concept of the likely character of nuclear war, the thesis adds nothing of great importance. Informal discussion with people who are not "expert" in any aspect of nuclear policy typically reveals the popularity of the belief that American society is assumed, hypothetically, to be in such sad condition after a large nuclear attack that any subsequent horrors deriving from climatological deterioration would be substantially irrelevant.[1]

Even if the public is relatively unmoved by the speculation among "experts" on possible nuclear winter phenomena, activist-proponents of the thesis have urged radical policy actions to address the new (or novel dimensions of the familiar) problem. In principle at least, the activist-proponents have a strong case to advance. It is important that all states should understand whatever can be understood in the absence of historical data (real experience) about the consequences of nuclear detonations, since all may be at risk to catastrophic climatic deterioration. Also, it is important that the nuclear-weapon states in particular recognize as best they are able what they do not understand and where the boundaries of key uncertainties probably lie. It is a moral, political and strategic duty of government that it not design forces, plan attacks, or execute strikes that would be needlessly damaging to human life and all that sustains it. Finally, to some extent depending upon the quality of scientific evidence available and the plausibility of extrapolation from an ever-imperfect data base, it is incumbent upon governments at least to consider policy responses on a scale appropriate to the level of plausible danger.

The Realm of Uncertainty

It seems unlikely that the nuclear winter studies conducted inside and outside of government will yield advice for policy-makers and defense planners superior to that available today on the basis of commonsense and intuition. Officials really do not need to be told either that the only way assuredly to be safe from nuclear weapon effects is not to fight a nuclear war, or that the full rigors of a nuclear winter would be as near a certainty as made no difference were one or more of the nuclear powers to seek to burn urban areas and to be indifferent in its targeting to the burning of forests and the lofting of dust particles into the upper atmosphere.

What substance is there to the claim that the widespread employment of nuclear weapons could trigger a nuclear winter? At the present time there appears to be little if any scientific disagreement over the state of our uncertainty, the sources of that uncertainty, or even the quality of the evidence that further study is likely to reveal. The Department of Defense Report on _The Potential Effects of Nuclear War on the Climate_ advises that:

> Although it is recognized that not all of the uncertainties could be reduced to uniform or perhaps even to acceptable levels, it is clearly possible to improve our knowledge of the climatic consequences of nuclear exchanges.[2]

The National Academy of Sciences, similarly, observes that:

> All calculations of the atmospheric effects of a major nuclear war require quantitative assumptions about uncertain physical parameters. In many areas, wide ranges of values are scientifically credible, and the overall results depend materially on the values chosen. Some of these uncertainties may be reduced by further empirical or theoretical research, but others will be difficult to reduce.[3]

A distinguished physicist has explained with exemplary clarity a basic, and probably enduring, difficulty with the nuclear winter thesis.

> The science of climate-modelling has not yet progressed far enough to predict with certainty, in the absence of a nuclear war, whether next winter will be mild or severe; it is unreasonable to expect the same science to give us reliable descriptions of the meteorology of a nuclear holocaust. The meteorological uncertainties of nuclear war will remain at least as great as the uncertainties of peacetime weather prediction.[4]

The U.S. Department of Defense has provided plain evidence that it takes the nuclear winter thesis seriously, believes that existing policy and technology trends already are responsive to climatic concerns, and admits very frankly just how broad is the current band of scientific uncertainty. Anyone predisposed to the view that the Department of Defense will not rise with due gravity to the issue of the possible climatic consequences of nuclear war, should read the following words very carefully.

> There is fairly general agreement, at the present time, that for major nuclear attacks the phenomena could proceed about as we have described, although there is also realization that important processes might occur that we have not yet recognized, and these could work to make climatic alteration either more or less serious. However, the most important thing that must be realized is that even though we may have a roughly correct qualitative picture, what we do not have, as will be discussed later, is the ability to predict the corresponding climatic effect quantitatively; significant uncertainties exist about the magnitude, and persistence of these effects. At this time, for a postulated nuclear attack and for a specific point on the earth, we cannot predict quantitatively the materials which may be injected into the atmosphere, or how they will react there. Consequently, for any major nuclear war, some decrease in temperature may occur over at least the northern mid-latitudes. But what this change will be, how long it will last, what its spatial distribution will be, and, of much more importance, whether it will lead to effects of equal or more significance than the horrific destruction associated with the short-term effects

> of a nuclear war, and the other long-term effects such as radioactivity, currently is beyond our ability to predict, even in gross terms.[5]

It would be difficult to state the problem of understanding the climatic implications of nuclear war more directly or honestly than this. The take-off points for strategic policy analysis have to be:

(1) Recognition that extensive further study is unlikely to resolve, as opposed to narrow, key scientific uncertainties;

(2) Realization that even if key scientific uncertainties are narrowed usefully, the phenomenon of nuclear war has to be treated as a range of policy possibilities, not as a single unique sequence of events;

(3) Appreciation of the implications of the very probable fact that the climatic consequences of nuclear war are most unlikely to be within unilateral American control.

Radical Solutions

As a matter of "elementary planetary hygiene, as well as elementary patriotism,"[6] Carl Sagan urges the nuclear-armed states to reduce the total levels of their nuclear arsenals to a safe level -- below or at the low end of the allegedly critical 500-2000 warheads range[7] -- where nuclear winter assuredly could not be triggered, regardless of the uncertainties of weather, targeting doctrines, and the unpredictable dynamics of armed conflict. This simple brute force approach has everything to recommend it save for practicality of negotiability and strategic policy prudence. Dr. Sagan has yet to reveal the faintest glimmer of a plausible theory explaining how the five principal nuclear-weapon states could agree upon a just allocation of very scarce nuclear firepower.

This author may be deemed unduly churlish in criticizing Dr. Sagan -- given that Dr. Sagan has helped bring to official and public notice a subject that everyone agrees is of the greatest importance. Nonetheless, Dr. Sagan's nuclear winter speculations transcend the realm of scientific claims, or even scientific guesswork, and lead him into the field both of strategic policy commentary and of policy advocacy that has profound strategic implications. Dr. Sagan will not agree, but the Reagan Administration has, in place, policies in major and minor key that are as responsive to nuclear winter anxieties as reasonably can be asked -- consistent with the foreign policy-supportive burdens that are placed on the U.S. armed forces. Moreover, those policies do accommodate the non-trivial problem of predictable reluctance to effect massive policy change on the part of other nuclear-weapon states.

Given the size of extant nuclear arsenals, and the enormity of the possible danger, one might argue that doctrinal and technological "fine-tuning" of the U.S. strategic forces is the equivalent of fiddling while Rome is at least in peril of burning. Jonathan Schell, whose book The Fate of the Earth was something of an emotional precursor to the more extreme of the scenarios sketched by proponents of the nuclear winter thesis, expressed his view of the contemporary situation in the following way:

> If a busload of people is speeding down a mountainside toward a cliff, the passengers do not convene a seminar to investigate the nature of their predicament; they see to it that the driver applies the brakes.[8]

Whether or not Schell's analogy is accurate, it is not unreasonable to argue that on the basis of the precept of prudence governments are obliged to assume at least a bad case and not better cases with respect to the consequences of nuclear war. Short of the event, no one will be able to demonstrate beyond doubt that the major quantitative parameters pertaining to nuclear winter effects are understood. Given the probable scope of the residual uncertainties -- uncertainties that may come to be dominated by guesses concerning Soviet nuclear policy -- the burden of proof must lie with anyone who seeks to argue that a nuclear campaign would not trigger catastrophic climatic deterioration.

Strategic Perspective

Nuclear winter, let it be emphasized, is not a subject of debate between the U.S. Government and concerned scientists outside of government. There is not a group of people in and around the Government attempting to find reasons to support the "good news" that fears of nuclear winter have been grossly exaggerated and that therefore the United States can wage a nuclear war after all in (highly) relative safety! Any country willing to gamble its future on a "single roll of the cosmic dice" with a nuclear first-strike, hoping through preemptive counterforce action so to disrupt another country's ability to retaliate that only "tolerable" damage would be suffered by return, almost certainly would be a country willing to risk the defeat in victory of nuclear winter.

Contrary to Dr. Sagan's assertion, it is not at all certain that "[w]e have...been constructing a Doomsday Machine."[9] Adverse changes in the global climate might prove to be quite sensitive to systematic, though individually modest, alterations in strategic weapon characteristics and tactics of employment. "Reasonable people" would not make such an assumption, but this author is not confident that Soviet leaders undeterred by the prospect of a massive U.S. nuclear strike back would be "reasonable" in the sense that the adjective is intended to imply. (After all, "reasonable people" should be deterred from waging nuclear war -- regardless of nuclear winter anxieties). American leaders have no reliable knowledge: (a) of what Soviet scientists believe they understand about the climatic consequences of nuclear war; (b) of what Soviet political and military leaders believe about such consequences; or (c) whether, if the Soviet Government believes there could be a severe problem, suitable policy, technological, and tactical remedies are considered in Moscow to be to hand.[10]

The technical and policy uncertainties will be such that great comfort should not be drawn from the following wry comment by Dr. Sagan:

> If a first strike gains no more than a pyrrhic victory of ten days' duration before the prevailing winds carry the nuclear winter to the aggressor nation, the "attractiveness" of the first strike would seem to be diminished significantly.[11]

Quite so --but that tantalizing "if" could be all important. Bereft of experience of nuclear war, Soviet leaders cannot know whether or not a military victory will be rendered pyrrhic by nuclear winter, but the risk may seem to be only a marginal addition to the risks to the Soviet state that repose for certain in U.S. (*inter alia*) strike-back capability. Quite apart from nuclear winter anxieties, both superpowers would have enormous incentives to exercise the maximum restraint in nuclear targeting consistent with an acceptable prospect of success in the military purposes pursued. Moreover, both superpowers have been fabricating strategic weapon and communication technologies that should facilitate the exercise of a very noteworthy level of discrimination in nuclear employment.[12]

If the perceived consequences of strategic nuclear inaction are judged to be sufficiently dire, by either side (the loss of NATO-Europe for the United States, or, in Soviet perspective, stalemate-defeat in a theater campaign or anticipation of a U.S. strategic nuclear initiative), policy-makers, one can predict, would find ample plausible grounds for discounting the nuclear winter thesis. Further study may show that systematic attention to nuclear winter phenomena in weapon design and targeting should reduce the danger very markedly, the danger may be believed to find expression in adverse effects measurable on a graph with a gentle slope rather than with a threshold beyond which lies a precipice, and last but by no means least, policy-makers on both sides may well find themselves so mesmerized by the prospective immediate horrors of the "nuclear exchange" that climatic catastrophe is too far down the queue of concerns to receive careful attention. There is a sense in which nuclear winter is, and is likely long to remain, a "wild card" inherently resistant to analysts looking for relevant advice for operational policy.

Policy Options: Real and Unreal

Useful light may be shed on the strategic policy implications of the nuclear winter thesis if one explores the choices theoretically open to a U.S. President who became convinced that the most severe of the possible climatic consequences of detonation of 500-2000 nuclear warheads would indeed occur. How could such a President address the problem? The policy options would be few.

(1) The United States could share its new scientific knowledge of nuclear winter effects with the whole world and seek to negotiate a total reduction in the world's nuclear arsenals of 96-99% (having in mind Carl Sagan's very approximate baseline figure of 50,000 nuclear

warheads, of all types and yields, for the global inventory).

A moment's reflection generates recognition of some non-trivial difficulties with this worthy idea. First, would the world's nuclear powers agree to such a draconian cut in their last line of deterrence/defense? Would existing ratios of nuclear firepower (measured how? -- equivalent megatonnage, megatonnage, warheads?) be preserved -- a principle which, however applied, would leave the smaller nuclear powers with no more than handfuls of weapons each. Second, very considerable uncertainty pertains to the size of the Soviet nuclear weapon arsenal. Soviet defense planners, culturally very comfortable with deceptive practices, would certainly discern some excellent strategic reasons for not disclosing the full size of their arsenal. Several hundred hidden weapons, intended to make a crisis or wartime _début_, could make all the difference among stalemate, defeat, or victory.

(2) The United States could decide upon near-total unilateral nuclear disarmament, in the event of a plainly predictable reluctance to cooperate fully in disarmament on the part of the world's other nuclear Powers. Such an option would lend itself to defense by powerful rhetoric with a high moral tone (reference could be made to Carl Sagan's idea of "elementary planetary hygiene" and even his notion of "elementary patriotism").

Unfortunately, aside from the more obvious problems for international order that such unilateral American nuclear disarmament would be bound to generate (which would likely include a rush to acquire independent nuclear forces on the part of allies [or erstwhile allies] of the United States now, probably suddenly, bereft of even a moderately implausible U.S. nuclear guarantee), this policy option simply would not meet the scale of the problem. The full rigors of a nuclear winter -- given the premise that 500-2000 detonations would trip the world over the abyss -- easily could be visited upon the world by the nuclear arsenals of the Soviet Union, France, China, Great Britain, and probably others. Moreover, drastic unilateral nuclear disarmament by the United States would be likely to have such a profound disordering impact upon the entire structure of international security, that the risks of major war (including nuclear war) would rise very markedly. People offering strategic advice, or advice for policy that has important implications for strategy, must never be permitted to forget that the key question in strategy is not "is it right," rather it is "will it work."

On the evidence of both history and commonsense it is as obvious as anything can be that heroic policy options (1) and (2) -- negotiated reductions to a level of nuclear arsenals below the calculated danger level, and unilateral U.S. nuclear disarmament -- whatever their sundry attractions, share the fundamental and fatal flaw that assuredly they will not work.

(3) Third, and finally, a U.S. President can seek cumulative alleviation, and perhaps one day a robust solution, to the nuclear winter problem through technology-led formal and functional nuclear disarmament. In short, the essentially technological problem of nuclear winter would be addressed by the technological response of strategic defense. This is not the place to argue the technical merits of the SDI. Suffice it to say that whether or not the SDI is able to disarm nuclear arsenals in functional terms, and/or to trigger a truly draconian scale of negotiated disarmament, the other options are not serious candidates for policy adoption.

Should further scientific study reveal that Dr. Sagan's 500-2000 (large) warheads (on cities) range is far more likely to be correct than incorrect, then it would have to follow that large-scale countercity nuclear strikes by any country and against any country or countries must be regarded as posing a potentially deadly threat to the United States. Thus far, for the most obvious example (and to ignore the problem of plausibility of scenario), it has always been appreciated that British or French nuclear action against the Soviet Union would be very likely to function as a catalyst for a Soviet-American "central" war, but the catalytic danger has been seen as residing in the probability, indeed high probability, of Soviet retaliatory strikes against the United States. An effectively scientifically verified nuclear winter thesis à la Sagan, would mean that the nuclear action of U.S. allies itself would place North America at terminal risk. In these circumstances there would be a great deal to be said in favor of the United States utilizing a globally effective (i.e. space-based, rapidly space-deployable, or space platform using) strategic defense architecture for the protection of the planet -- regardless of the flag of the attacker or the destination of the attack. The implications of this logic for coalition politics scarcely need elaboration.

Defining the Problem

In a more realistic vein of discussion, it is more likely than not that several years, and many scientific studies, from now, the President of the day will be told that:

(1) Nuclear winter may not be a single possibility, to be triggered if some "magic fraction" of the world's nuclear arsenals are detonated so as to produce the requisite quantities of smoke, soot, and dust. Instead, there may be no predictable "threshold," but rather a cumulative deterioration of the climatic condition supportive of life on Earth. In other words, there probably is not a unique "danger zone" -- be it 500-2000 warheads or another range -- which means that there is no absolutely "safe" quantitative level of nuclear warfare, at least beyond the employment low-yield of "tactical" weapons.

(2) The uncertainties pertaining to the climatic effects of nuclear war remain, and will long remain, sufficiently large that, in the absence of a definitive political solution to problems of international security (and it is wise to exclude political miracles from long-term defense planning), it is prudent, indeed responsible, to assume that (a) adjustments in weapons technology, force structure, and targeting plans, might help, and that (b) efforts to effect some negotiated cooperation in the management of the nuclear arms race also could be useful. But, it is no less prudent to remember that even wholesale reconstruction of the U.S. nuclear arsenal and targeting plans might be quite without value vis à vis nuclear winter effects, if other Powers do not follow suit (and even if they do, the changes may well be insufficient to preclude climatic catastrophe).

(3) Great Powers have never negotiated away whole classes of weapons that they believed to be prospectively useful for political intimidation in time of crisis or for military success in war. The only way in which the more dangerous features of the nuclear age might be repealed, or effectively repealed, is through the development of weapons that would deprive nuclear offensive forces of their presumed political and military value. This has to mean the SDI. There is no confusion here between logical necessity and technological/tactical practicality. It is not suggested that the SDI must "work" on a scale such as

to render offensive nuclear arms impotent and obsolete, because alternative answers to the nuclear danger are unavailable. The argument is not that the SDI must work because nothing else will -- only that if the SDI does not work on a comprehensive scale, there is no alternative.

U.S. Policy Today

This author has no mandate to defend either the nuclear policy of the U.S. Government, or its current approach to the nuclear winter thesis, but he can find little in official policy that merits criticism.

Consistent with posing the kind of threats needed to maintain stability in deterrence for the prevention of war, the United States is endeavoring to field forces and develop targeting plans that would, if ever executed, inflict the least unwanted collateral damage upon targets that could provide the most potent fuel base for adverse climatic effects. Over the past twenty years there has been a massive reduction in U.S. nuclear megatonnage (it is the higher yield weapons that are particularly troubling *vis à vis* high altitude atmospheric disturbance), and urban-area targeting has been radically deemphasized. As weapon accuracies continue to improve weapon yields can diminish, while some "point targets" should lend themselves to destruction by non-nuclear bombardment.

For more than a decade U.S. nuclear weapon employment policy has emphasized the objectives of controlling escalation and restoring deterrence. In the event that pre-war deterrence should fail, Soviet operational strategy and flexibility may or may not be conducive to early war termination (with most or many nuclear weapons held in reserve).[13] But, U.S. concern -- expressed in the C^3I modernization program and force survivability measures -- to maximize the possibility that few rather than many nuclear weapons would be used in a war of shorter rather than longer duration, plainly is prudent and sensible.

The SDI is a responsible endeavor to explore the feasibility of creating physical barriers against nuclear attack and its effects (including nuclear winter). If the SDI is shown to have technical credibility in a relatively modest deployment in defense of retaliatory forces and C^3I assets, it will strengthen the stability of the nuclear deterrence system; if cost-effective defense of urban areas is feasible, the nuclear offensive arsenals that carry the threat of nuclear winter should prove very negotiable indeed for drastic reduction. Should deterrence fail and should many nuclear weapons be fired at cities, strategic defenses may be capable of incapacitating a large fraction of those weapons, thereby reducing the climatic danger.

Notwithstanding the many scientific uncertainties that surround the nuclear winter thesis, on the policy side it is plain that any intended alleviation or solution that fails to encompass the arsenals of all nuclear-weapon states has to be judged structurally inadequate. Relatively little has been said here directly about Soviet attitudes towards the nuclear winter thesis. In principle at least, the thesis has to catch the Soviet attention. The claim by Dr. Sagan that military success in a preemptive first strike could be followed by an unfolding general climatic defeat ten days later is an arresting one.[14] Furthermore, whatever may be the angle of the slope of the curve of temperature drop caused by nuclear weapon effects, Soviet agriculture is more vulnerable even to a small scale of climatic deterioration than is American agriculture. In other words, the Soviet Union is going to be present at the site of a nuclear winter before the United States -- though the prospective difference probably is not of policy significance for today.

Always granting the distant possibility of an agreeable surprise, there are no grounds known to this author that would suggest any Soviet willingness to reconsider their military policy in the light of the nuclear winter thesis. Indeed, the evidence to date suggests rather that the Soviet Government views nuclear winter as a useful concept for the unilateral embarrassment of the open societies of the West. Given that the Soviet Union has expended enormous effort over the past twenty years to secure the military basis for a credible claim to parity in superpower status, consideration of the distant and highly uncertain possibilities of nuclear winter are not likely to be permitted to figure in the broad shaping of military doctrine and posture.

One might speculate as to the possibility of the nuclear winter thesis encouraging a new style in planning for nuclear warfare. Specifically, if there is a predictable "threshold" for nuclear winter, and if the enemy agrees on where that threshold lies, then it might be feasible to launch a nuclear attack that approached, but stayed safely below, the threshold -- in the confident knowledge that the enemy dare not strike back. As "salon strategy," this idea is not uninteresting, but as prospective operational reality it is thoroughly unpersuasive. No country will know, for certain: (a) whether there is a potential climatic discontinuity of "threshold" character; (b) if there is such a threshold, where it lies; or (c) what the enemy truly believes. Furthermore, it is probably safe to assume that Soviet political and military leaders will mirror-image their American opponent. Knowing that they would not be deterred from striking back after a hypothetical U.S. coercive counterforce attack below the presumed nuclear winter threshold, they would credit an American President with a like determination. It would be contrary to what is believed in the West about the Soviet way of war, to entertain the notion that the Soviet Union would choose to launch a very highly constrained attack in the hope that self-deterrence in Washington would foreclose upon a strike back (for military-political reasons, for honor, or simply for revenge).[15]

Conclusions

The inescapable conclusions of this analysis are the following:

(1) If an attacker is willing to hazard his state and society to a near-certain weight of retaliation in the 3,000-4,000 warhead range, and a possible weight in the 4,000-8,000 warhead range, it is less than obvious that the inherently uncertain prospect of climatic deterioration will be permitted to count in his calculations. Soviet political leaders and defense planners may conclude, in company with George Rathjens, that "[w]hen all of these concerns are combined [air movements from the oceans to the continents and from South to North, and 'the effects of the patchiness of the smoke cover, the heat capacity of the land surface, and other restoring forces...'], it appears that the temperature decrease may not exceed a few degrees. This would not add very much to the terrible destructiveness of an all-out nuclear war."[16]

(2) Drastic change in U.S. nuclear policy today is not required. Moreover, it could not work (nuclear winter is one of those "many Powers or none" problems). More to the point, perhaps, drastic unilateral change in the weight of the U.S. nuclear arsenal would trigger highly dangerous new instabilities. Paradoxically, an American panic response to the nuclear winter thesis could bring

about the very event dread of which had motivated the policy change.

(3) Technological and tactical change at the margin, by all the nuclear Powers, may help to alleviate the problem. Officials are obliged to behave as if this were true. It so happens that purely strategic considerations already have moved the United States and even the Soviet Union some way down the road of climatically less threatening nuclear doctrines and postures. For reason of their relatively small scale, the nuclear forces of France, Britain, and China essentially are locked into the kind of countervalue targeting doctrines that would be most likely, in execution, to promote climatic disaster.

(4) Pending invention or evolution of a definitive political solution to nuclear dangers, the only responsible alternative that may be available is provision of technological barriers to nuclear detonations -- a weaponized SDI. If one rejects the SDI road, for whatever blend of reasons, then one is obliged to recognize nuclear winter as a possibility that is inherent in our nuclear condition (not nuclear problems).[17]

(5) For those still in need of enlightenment on nuclear strategy, the nuclear winter thesis should serve as the final nail in the coffin of the concept of mutual assured destruction (MAD) and its variants.[18] A small but critically important gleam of certainty shines amidst the

plethora of uncertainties referred to in this discussion: targeting urban areas is a positive invitation to climatological disaster. Needless to say, perhaps, proponents of the MAD concept will not agree with this judgment upon the merit of their position. It is their belief that nuclear weapons have no operational value as weapons of war, and that American declaratory strategy over the past decade, from the Schlesinger Doctrine, so-called, of 1974, through the "countervailing" and "prevailing" strategies of Secretaries of Defense Harold Brown and Caspar Weinberger, respectively, essentially constitute dangerous and futile attempted evasions, or denials, of a MAD reality. On balance, the nuclear winter thesis is welcomed by the mutual vulnerability school of thought as underlining, allegedly unmistakeably, the truth in their position.

The nuclear winter thesis is not going to be verified beyond doubt by scientific research. But, it is a possibility that the prospect of very severe adverse climatic effects being triggered by nuclear use on a scale trivial compared to the potential in the world's nuclear arsenals, might be rendered very plausible indeed by further study. The strategists of all nuclear-weapon states should not be preemptively dismissive of the possibility that even very carefully conducted counterforce strikes, if on a large scale (several thousands of detonations at ground or very near ground level), might have the effect of transporting a lethal quantity of dust into the upper atmosphere. Furthermore, direct concern about the transportation of dust, and smoke from forest fires, would have to be augmented by the familiar anxieties over the risks of escalation to strikes against targets with a much more potent fuel base.

The case for the SDI far transcends nuclear winter possibilities, but recognition of those possibilities should strengthen U.S. determination to pursue effective strategic defense technologies in the spirit of President Reagan's initial vision of March 23, 1983. The only way in which the hypothetical climatic danger might be alleviated on a dramatic scale is by the provision of physical barriers against nuclear detonations. It should go without saying that the deterrence of war must not be weakened in the interest of protection in war, and it is possible that the SDI may fail to provide the technical basis for an orderly transition to a security condition of dominant defenses. Given what may be at stake, the strength of the case for making the attempt should be self-evident.

NOTES

I would like to thank Keith B. Payne and Rebecca V. Strode for their valuable contributions to this essay.

1. For some people the *global* dimension of the nuclear winter thesis is critical for its uniqueness. Not merely would the (guilty) superpowers suffer fatal damage, but the consequences of their sins or errors would be visited upon all forms of life around the globe. The global "doomsday" hypothesis is seen not only as physically distinctive from long-standing arguments about the horrors of nuclear war, but also as morally distinctive.

2. Report to the U.S. Congress (Washington, D.C.: Department of Defense, March 1985), p. 8. (Hereafter cited as DoD Report).

3. The National Academy of Sciences, *The Effects on the Atmosphere of a Major Nuclear Exchange* (Washington, D.C.: National Academy Press, 1985), p. 9.

4. Freeman Dyson, *Weapons and Hope* (New York: Harper and Row, 1984), p. 21.

5. DoD Report, p. 2.

6. Carl Sagan, "Nuclear War and Climatic Catastrophe," *Foreign Affairs*, Vol. 62, No. 2 (Winter 1983/84), p. 286.

7. Ibid., p. 275.

8. (New York: Knopf, 1982), p. 227.

9. "Nuclear War and Climatic Catastrophe," p. 285.

10. See DoD Report, pp. 16-17.

11. "Nuclear War and Climatic Catastrophe," pp. 276-77.

12. Nonetheless, it would be foolish to assume a certainty of centralized control in nuclear war. See Desmond Ball, *Can Nuclear War Be Controlled?* Adelphi Papers No. 169 (London: IISS, Autumn 1981); and Paul Bracken, *The Command and Control of Nuclear Forces* (New Haven, Conn.: Yale University Press, 1983). On the U.S. C^3I modernization program see the testimony of Donald C. Latham, Deputy Under Secretary of Defense (C^3I), in U.S. House of Representatives, Committee on Appropriations, Subcommittee on the Department of Defense, *DoD Appropriations for 1985*, *Hearings*, Part 4, 98th Cong., 2nd sess. (Washington, D.C.: USGPO, 1984), pp. 591-685; and Caspar W. Weinberger, *Annual Report to the Congress,*

Fiscal Year 1986 (Washington, D.C.: USGPO, February 4, 1985), pp. 216-19.

13. See Benjamin S. Lambeth, "On Thresholds in Soviet Military Thought," The Washington Quarterly, Vol 7, No. 2 (Spring 1984), pp. 69-76; and Robbin F. Laird and Dale R. Herspring, The Soviet Union and Strategic Arms (Boulder, Colo.: Westview, 1984), Chapter 3.

14. "Nuclear War and Climatic Catastrophe," pp. 276-77.

15. See John Erickson, "The Soviet View of Deterrence: A General Survey," Survival, Vol. XXIV, No. 6 (November-December 1982), pp. 242-51.

16. George W. Rathjens and Ronald H. Siegel, Review of Paul R. Ehrlich, et. al., The Cold and the Dark: The World After Nuclear War (New York: Norton, 1984), in Survival, Vol XXVII, No. 1 (January/February 1985), p. 43. Rathjens and Siegel proceed to argue that "...what one has in The Cold and The Dark is an example of 'worst case' analysis run wild, inadequately qualified by discussion of uncertainties -- justified (to some extent explicitly) by the argument that in matters of risk, policy should be based on worst-case analysis; never mind that there may be costs to risk avoidance." P. 44.

17. A well-argued case for resisting the attractions of "atomic escapism" is the Harvard Nuclear Study Group, Living With Nuclear Weapons (New York: Bantam, 1983), particularly Chapter 11.

18. The most rigorous of the contemporary standard bearers for MAD is Robert Jervis. See his recent book, The Illogic of American Nuclear Strategy (Ithaca, N.Y.: Cornell University Press, 1984), and article "MAD is the best possible deterrence," Bulletin of the Atomic Scientists, Vol. 41, No. 3 (March 1985), pp. 43-5. His policy arguments are fundamentally irresponsible and offer nothing of direct value for policy-makers. But, his critique of extant policy is tautly constructed and is helpful for those in and out of government who are concerned to submit the orthodoxy of the day to basic review.

TESTIMONY SUBMITTED BY
ANTHONY ELLSWORTH SCOVILLE

TO
THE SUBCOMMITTEE ON NATURAL RESOURCES,
AGRICULTURAL RESEARCH AND ENVIRONMENT
of
THE COMMITTEE ON SCIENCE AND TECHNOLOGY

AND TO
THE SUBCOMMITTEE ON ENERGY AND THE ENVIRONMENT
of
THE COMMITTEE ON INTERIOR AND INSULAR AFFAIRS
U.S. HOUSE OF REPRESENTATIVES

THE NUCLEAR WINTER:
An Analysis of a Report To The United States Congress
by
Secretary of Defense Caspar W. Weinberger
on
"The Potential Effects of Nuclear War on The Climate."

MARCH 14, 1985

Mr. Chairman, I commend you for holding this hearing on the "Nuclear Winter". I want to express my concern over Secretary of Defense Weinberger's report to Congress "The Potential Effects of Nuclear War on The Climate" . While serving as a Technical Consultant to the House Science and Technology Committee I had the opportunity study the Greenhouse Effect which may result from fossil energy use; more recently I have been writing a book surveying potential causes of world climate change including the "nuclear winter". Based on my experience I believe the report is a gravely inadequate response to the mandate of Section 1107 of the 1985 Department of Defense Authorization Act. The report seriously underestimates the likelihood of a nuclear winter and its implications for US arms control and defense policy.

First, while concluding that

> "Even with widely ranging and unpredictable weather, the destructiveness for human survival of the less severe climatic effects might be of a scale similar to the other horrors associated with nuclear war.", (p.9)

the report severely criticizes the seminal TTAPS study by Turco, Sagan and their colleagues because the latter is based on a one-dimensional model of the atmosphere. Nowhere does the Secretary mention the more recent work by Stephen Schneider and his colleagues using the three-dimensional atmospheric model developed at the National Center for Atmospheric Research. They conclude that

> "continental interiors may cool by 40°C or more in July (similar to the land values of Turco _et al._) but land surfaces can cool more quickly, to below freezing-even near coasts- in only a few days. This is a consequence of our resolution and of the separation of the surface and lower atmospheric temperature calculations, illustrating that adding detail to the calculations will not necessarily make the problem less severe." (Nature 310, 626, 1984)

I should add that the strong temperature contrasts between land and the oceans suggest the likely occurrence of hurricane strength storms along coasts where human populations are concentrated.

Second, even the report's conclusion that "severe climatic effects might be of a scale similar to the other horrors associated with nuclear war" is flawed in part because the report, by its own admission, deliberately ignores the directive of sec. (b)(1) to consider the "environmental and biological consequences". Conventional analyses of the casualties resulting from a major nuclear exchange between the US and the USSR range from a low of 200 megadeaths worldwide up to two billion dead resulting from the combined effects of fire, blast, and radiation. Unprecedented though such losses would be, approximately two to three billion people were expected by these analyses to survive a nuclear halocaust. The "nuclear winter" with its attendant subfreezing temperatures and crop failures even in tropical regions threatens mass starvation the world over. In the words of the panel of biologists at the Conference on the Long-Term Worldwide Biological Consequences of Nuclear War:

> "In any large scale nuclear exchange between the superpowers, global environmental changes sufficient to cause the extinction of a major fraction of the plant and animal species of the Earth are likely. In that event, the possibility of the extinction of *Homo sapiens* cannot be excluded." (*Science*, Vol. 222, p. 1300)

The report is further flawed when it suggests that these environmental and biological consequences of "newly postulated climatic effects" would only occur "at possible upper extremes indicated by some analyses" (p.ii). The TTAPS report was startling precisely because it concluded that a nuclear winter could occur if less than 1% (100 megatons) of world strategic nuclear arsenals were detonated over urban targets.

Since the TTAPS report was published evidence has come forward that the effects of a nuclear winter would be prolonged up to four years after a nuclear exchange because increased snow and sea ice particularly in high latitudes would reflect more summer sunlight than normal. As stated by Alan Robock of the Univ. of Maryland Dept of Meteorology,

> "the response of the climate to nuclear war is longer and larger than previously found by Turco *et al.*(TTAPS) who did not include these (snow-ice) feedbacks. It would presumably be very difficult to grow crops not only in the summer of the year that the war began, but also in the summer of the next year, with temperatures over land almost 6°C (>10°F) colder than normal." (Nature,310, p.668)

During this period of prolonged cold stretching over several years, the viability of seeds would sharply diminish reducing the germination of crops even were young plants not hampered by cold.

In sum, Secretary Weinberger's report does not provide an adequate review of current technical knowledge of the climatic and environmental effects of a "nuclear winter".

More serious, however, is the failure of the report to address paragraphs (b)(2) and (b)(3) concerning the policy implications of a nuclear winter. Instead, the report takes the position that possible climate change after nuclear war merely supports current nuclear policies. Thus it states, "We conclude --- that these three elements (deterrence, arms control, and the Strategic Defense Initiative) and the initiatives we are taking for each of them, remain fundamentally sound." (p.10) The report does not seriously consider the fact that the nuclear winter introduces a new concept of deterrence: namely, self-deterrence. As outlined in the attached article, "Nuclear Self-Deterrence", nuclear aggression can be deterred by the knowledge that any nation who launched a nuclear first strike of sufficient size to incapacitate either superpower would experience starvation of its entire population even if the target nation never launched a single missile in retaliation. Thus nuclear self-deterrence opens up the possibility of dramatic unilateral reductions in nuclear arms as an indication of good will leading to the negotiated elimination of all nuclear weapons.

Secretary Weinberger criticizes "self-deterrence" because of the alleged scientific uncertainties of climate models and because the Soviets' would not find self-deterrence credible given these "uncertainties". I have already discussed the technical inaccuracies in his analysis of our scientific understanding of climate after nuclear war. Furthermore, Soviet scientists, high-level academicians not mere "propagandists" as the Secretary suggests, have spoken out forcefully on the threat of the nuclear winter. That Soviet leaders may recognize the threat as well is demonstrated by the participation of these scientists is the live television conference which occurred as part of the October, 1983 Conference on The World After Nuclear War. Such participation would surely not have occurred without political permission from the highest level.

Implicitly the Secretary also dismisses nuclear self-deterrence with the assertion:

> "We believe that threatening civilian populations is neither a prudent nor a moral means of achieving deterrence, --- our strategy consciously does not target population and, in fact, has provisions for reducing civilian casualties." (p.11)

Nowhere in his report does the Secretary explain how one might prevent the mere 100 megatons required to initiate a nuclear winter from striking populated areas when so many military targets in the Soviet Union and Europe are located in or near urban areas.

Rather, he seems to draw a conclusion precisely opposite to self-deterrence when the report says:

> "that proposals which would 'freeze' development of modernized systems would also stop what has been a continuing trend in our capability--development of systems which are more discriminating and thus more restrictive in both local and global effects. We must avoid constraints that would force us to use weapons of high yield or unconfined effects." (p.13)

This statement comes close to using the nuclear winter as a rationale for developing a nuclear war fighting capability--an extraordinarily ominous signal which must surely be perceived as a deadly threat by Soviet leaders.

Similarly, the Secretary argues that the Strategic Defense Initiative (Star Wars) "may provide a greater mitigating effect on atmospheric consequences than could result from any level of reductions likely to be accepted by the USSR in the near term." (p.13) It is incomprehensible how the Secretary believes that it will be possible to develop the enormously complex and error prone computer programs required to command and control a space-based missile defense system when he so seriously doubts the relatively simple computer models of the atmosphere which predict the occurrence of a nuclear winter.

President Reagan is correct when he seeks some alternative to the balance of terror which has been the basis of nuclear deterrence for the last forty years. Sooner or later that delicate balance will be upset with catastrophic consequences for mankind. But he is dangerously deluded when he concludes that there is a technical fix to the political problem resolving superpower conflicts. There is no technical fix, whether in the guise of conventional "mutual assured destruction" or a microchip moat of strategic missile defenses, which will work perfectly, forever--as it must-- now that mankind knows the secret of nuclear energy.

Knowledge of the nuclear winter provides an alternative. It tells us that it is possible to dismantle all nuclear weapons with the assurance that any nation which violated the prohibition would be deterred by the assurance of suicide.

Secretary Weinberger's report on the climatic effects of nuclear war is alarming. It suggests that our vision of superpower defense and foreign policy is so astigmatized by pre-nuclear catagories of deterrence and counterdeterrence that intelligent men can seriously employ the nuclear winter to rationalize an acceleration of the strategic arms race which has emperiled mankind for forty years. It suggests that mankind may not negotiate a path to the post-nuclear era--in time.

Once again, Mr. Chairman, I commend you for holding this hearing on "The Potential Effects of Nuclear War on The Climate". In addition to this testimony I would like to submit for the record the attached article, "Nuclear Self-Deterrence" in which I discuss some of the policy implications of the nuclear winter. I also submit here a brief biography for your information.

Thank you, Mr. Chairman.

Answer to Representative McCain (written March 25, 1985)

There are vastly too many nuclear weapons in the world -- a contention with which Secretary Perle, in his testimony, agrees. It follows that either side could make major unilateral divestments of nuclear weapons without harming its strategic retaliatory capability. One side could make a significant divestment as a test, to probe the sincerity of the other. If no response were forthcoming, it would be possible to reaccession the nuclear weapons. Some of the purported advantages of such a unilateral non-negotiated policy have been outlined by Mr. Reagan's own Director of the Arms Control and Disarmament Agency, Mr. Kenneth Adelman ("Arms Control With and Without Agreements," Foreign Affairs, Vol. 63, No. 2, Winter 1984/85, pp. 240-263). Such unilateral steps on the part of the United States led in 1963 to reciprocal unilateral steps by the Soviet Union -- in both cases to stop above-ground nuclear testing. Before the year was out, the 1963 Limited Test Ban Treaty had been signed. The Soviets have, for three years, stated and implemented a unilateral policy of not further testing anti-satellite weapons systems. Both nations have taken unilateral steps of differing degrees of seriousness and effectiveness over the years. I note that Secretary Perle spoke more than once about the steps that the Reagan Administration has made unilaterally to reduce its stockpiles of nuclear weapons, although some of the assertions in his testimony, and in the Pentagon's Nuclear Winter report on the same subject, are deeply misleading.

I recognize that the phrase "unilateral arms reductions" has in the minds of some people, some taint of Munich about it, some propensity for surrender. But in a world with 55,000 nuclear weapons, we must carefully re-examine all the conventional wisdom.

Answer to Representative McCain (written March 25, 1985)

The above remarks are to give a feeling of how unilateral steps could be safely undertaken to reduce the present dangerously, grotesquely bloated nuclear arsenals. However, Congressman McCain's question is about my own views. While I do not see how carefully choreographed unilateral steps could do any damage -- indeed, they could even do significant good -- I do not see any urgent argument in their favor. My recommendation is for serious bilateral -- not unilateral -- steps, with adequate verification, to make massive reductions in the instruments of planetary suicide that the United States and the Soviet Union have foolishly stockpiled. It is equally in the best interests of both nations.

-- Carl Sagan

University Scientists in Nuclear Winter Research

Mr. Lujan: How many university scientists are currently being supported by the DoD Nuclear Winter program?

Mr. Perle: Without conducting an audit of current activity funded by the Department, it would be difficult to estimate the number of university affiliated scientists engaged in full or part-time work on this issue. If known however it would not represent the level of effort indended by the Interagency Research Program, which begins in FY 1986.

The Administration's FY 1986 budget request for Nuclear Winter research is $5.5 million. The DoD share of that request is $2.5 million. At this time we have identified about $500,000 for research activity outside of Government. For the most part, we plan to direct these funds toward universities possessing specialized expertise in the phenomena commonly associated with the Nuclear Winter hypothesis. No doubt the Department of Energy ($2.5 million) and the National Science Foundation ($0.5 million) plan to direct some of their research to academia as well.

National Academy of Sciences' Study

Mr. Lujan: How many university people were involved in the National Research Council Study for the National Academy of Sciences on Nuclear Winter?

Mr. Perle: The National Academy's study began early in 1983 at the request of the Defense Department and was completed by December 1984. The Department had no hand in the management of the study nor the preparation of the report.

A precise accounting of the number of university affiliated scientists contributing to the study would be difficult to estimate without a careful audit of the full and part time participants by the Academy. I can observe, however, that the non-government scientific community was well represented on the study. For example, the Committee charged with the responsibility for the report was comprised of 18 scientists from academia, government and industry -- half were individuals affiliated with universities including the Committee's Chairman, Dr. George F. Carrier of Harvard's Applied Sciences Division.

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